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THE LOESS-PALAEOSOL SUCCESSION OF KURTAK (Yenisei basin, Siberia): A REFERENCE RECORD FOR THE KARGA STAGE (MIS 3)

■

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ABSTRACT

The loess-palaeosol succession of Kurtak, along the western slope of the Yenisei Valley, is one of the best documented Late Pleistocene sequences in southern Central Siberia. The present paper deals with the Kurtak Pedocomplex and with the Chani Bay Complex preserved on the plateau and in a lateral depression respectively, which correspond to the Karga Stage (MIS 3). For this sequence we obtained a detailed palaeoclimatic succession based on pedological and palynological data recording 14 short interstadial periods. The chronology of this record is well established by ca 100 radiocarbon dates on charcoal and wood remains, ranging from 42,520 to 25,710 BP. Botanical analysis shows a steppe-like vegetation with small tree populations (spruce, pine, birch) in lateral valleys during the colder periods. During the interstadial episodes spruce populations grew denser in the valleys, while scattered spruce, larch and pine trees expanded on the plateau. Therefore, the Kurtak Pedocomplex and Chani Bay Complex provide a unique climatic record for MIS 3, similar to the middle pleniglacial succession of the Dinkel Valley in the Netherlands and to loess-palaeosol records of Eastern and Central Europe. This means that the Siberian record shows a climatic sequence of global significance, and that the environmental conditions during MIS 3 were highly unstable at the Eurasian continent.

Key-words: Loess, Central Siberia, Karga Stage (MIS 3), climatic succession, palynology, radiocarbon chronology.

RÉSUMÉ

LA SÉQUENCE LOESSIQUE DE KURTAK (BASSIN DE L'INÉISÉI, SIBÉRIE) : UN ENREGISTREMENT DE RÉFÉRENCE POUR LE STADE DE KARGA (SIM 3)

La succession pédosédimentaire de Kurtak, sur le versant occidental de la vallée de l'Inéiséi, constitue l'une des séquences loessiques les mieux documentées pour le Pléistocène supérieur en Sibérie centrale. Le présent travail découle d'une approche multidisciplinaire du Complexe de Kurtak et du Complexe de Chani Bay préservés respectivement en position de plateau et dans une dépression latérale. Un enregistrement paléoclimatique détaillé est fourni pour le Stade de Karga (SIM 3) sur la base de données pédologiques et palynologiques qui mettent en évidence 14 épisodes interstadiaires de courte durée. La chronologie de cet enregistrement est fondée sur une centaine de dates radiocarbone entre 42.520 et 25.710 BP obtenues sur des restes de bois et du charbon de bois. Les données paléobotaniques indiquent une végétation de type steppique associée à de petites populations d'épicéa, de pin et de bouleau dans les vallées latérales au cours des épisodes froids. Pendant les épisodes interstadiaires, les populations d'épicéa deviennent plus denses dans les vallées tandis que l'épicéa, le mélèze et le pin se répandent sur le plateau à l'état dispersé. Le Pédocomplexe de Kurtak et le Complexe de Chani Bay constituent ainsi un enregistrement unique pour le SIM 3, comparable à la succession du pléniglaciaire moyen dans la partie orientale des Pays-Bas (Dinkel Valley) ainsi qu'à certains enregistrements loessiques d'Europe centrale et orientale. Ces similitudes soulignent le caractère global de la séquence climatique sibérienne ainsi que la prédominance de conditions environnementales hautement instables au cours du SIM 3 à l'échelle du continent eurasiatique.

Mots-clés : Loess, Sibérie centrale, Stade de Karga (SIM 3), palynologie, séquence climatique, chronologie ^{14}C.

1 - INTRODUCTION

The Kurtak region is located on the western slope of the Yenisei Valley (Siberia), ca 120 km south of Krasnoyarsk (lat. 55° 20' N, long. 91° 50' E); it includes a complex Quaternary succession including a thick Middle and Late Pleistocene loess cover exposed along the Krasnoyarsk dam lake (fig. 1). During the 1980's, systematic geological studies in connection with archaeological survey work enabled the establishment of a detailed regional stratigraphic framework (Drozdov *et al.,* 1990; Derevianko *et al.*, 1992). This work was completed during the

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last decade by multidisciplinary and international field studies focusing on the loess cover, which led to a high-resolution Late Pleistocene sequence for southern Central Siberia (Drozdov *et al.*, 1999; Chlachula, 2003). This paper deals mainly with the Kurtak Pedocomplex and the Chani Bay Complex, two complementary units from the middle part of the loess succession which provide a unique stratigraphic, palaeoenvironmental and chronological record for the Karga Stage (MIS 3), also known as Karginsky Interstadial (Arkhipov *et al.*, 1986; Velichko, 1992). The importance of this record is increased by the geographical position of the Kurtak region: close to the centre of Eurasia, at a distance of ca 2,000 km from the Arctic Ocean. In addition, we obtained for the Kurtak climatic succession a chronology based on a long and unique series of radiocarbon dates. This is very important for a proper understanding of continental climate dynamics during MIS 3, a period for which well dated high resolution climatic sequences are rare in Eurasia (Shackleton *et al.*, 2004).

2 - GEOGRAPHIC SETTING

Kurtak is located in the northern part of the Minusinsk Basin drained by the Yenisei River (fig. 1). This basin corresponds to a tectonic depression below 400 m a.s.l. extending to the north of the Western Sayan Ranges which culminate around 2,900 m a.s.l. near the border with Mongolia. The Minusinsk Basin is limited by highlands between 800 and 1,500 m: the Kuznetsky Alatau towards the west and the foothills of the Eastern Sayans towards the east. To the north, the depression is separated from the Krasnoyarsk area by the Solgonsky Hills with altitudes below 900 m.

The Upper Yenisei Basin has a cold continental climate with mean temperatures of -18.2° in January and +17.6° in July. The annual precipitation at Balachta near Kurtak, ranges between ca 300 and 600 mm/yr. Most of the rain falls during the summer and is generally accompanied by thunderstorms. During the winter the snow mantle is shallow (Rozov *et al.*, 1988; Derevianko *et al.*, 1992). In the Upper Yenisei Basin precipitation varies significantly depending on the topography, with a minimum of about 200 mm/yr in the centre of the Minusinsk depression and a maximum between 800 and ca 1,500 mm/yr on the Western Sayans and on the highlands surrounding the depression.

The distribution of the vegetation is clearly related to the precipitation pattern. This results in the development of steppe in the southern part of the Minusinsk Basin, of forest-steppe in the northern part of the depression and of mixed southern taiga on the foothills of the Sayans and on the Solgonsky Hills (Suslov, 1961). The precipitation and vegetation patterns also determine the nature and distribution of the surface soils. According to the Russian Soil Map (Fridland, 1988), Kurtak is situated in an area with podzolised chernozem in association with leached chernozem under forest-steppe. To the north, and on the foothills of the Sayans, leached chernozem is dominant under taiga, while in the southern part of the Minusinsk Basin ordinary chernozem and southern chernozem form the main soils of the steppe area.

3 - GEOLOGICAL SETTING

3.1 - REGIONAL BACKGROUND

The Kurtak region belongs to the northern part of the Minusinsk Basin. This is a depression formed during the Pleistocene by neotectonic movements which have led to the development of a polygenetic system of alluvial, lacustrine, colluvial and aeolian deposits along the western slope of the Yenisei Valley. Loess originating from the local alluvial plain was distributed over most of the land during the Middle and Late Pleistocene, mainly on the western slopes where the loess cover reaches thickness up to 40 m. The significance of the Quaternary deposits of the northern Minusinsk Basin was established during the 1980's near the village of Kurtak (Drozdov *et al.*, 1990). At this locality, water of the Krasnoyarsk reservoir has eroded steep walls in the Quaternary deposits preserved at the edge of the valley slope on top of high and very high terraces, between 60 and 110 m above the valley floor. This complex sequence, open in five sectors over a distance of nearly 20 km along the banks of the lake (fig. 2a), brings together loess and colluvial deposits mainly ascribed to the Middle and Late Pleistocene based on palaeontological, geomorphological and palaeomagnetic data (Drozdov *et al.*, 1990; Derevianko *et al.*, 1992).

In the southern part of the Kurtak area, the Trifonovka and Kurtak sectors give access to a ca 15 m thick loess cover dating from the second half of the Late Pleistocene. In the central part of the Kurtak area the Pleistocene deposits of the Sukhoy Log sector, present on top of

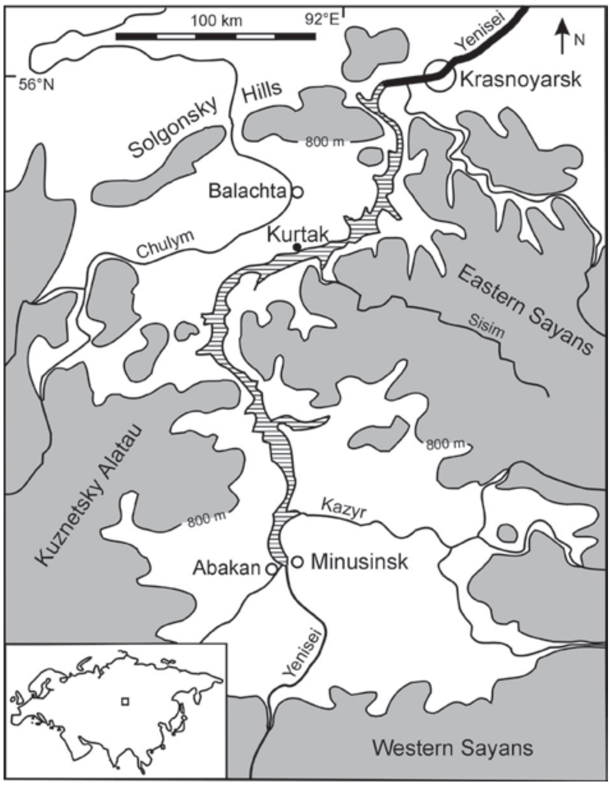
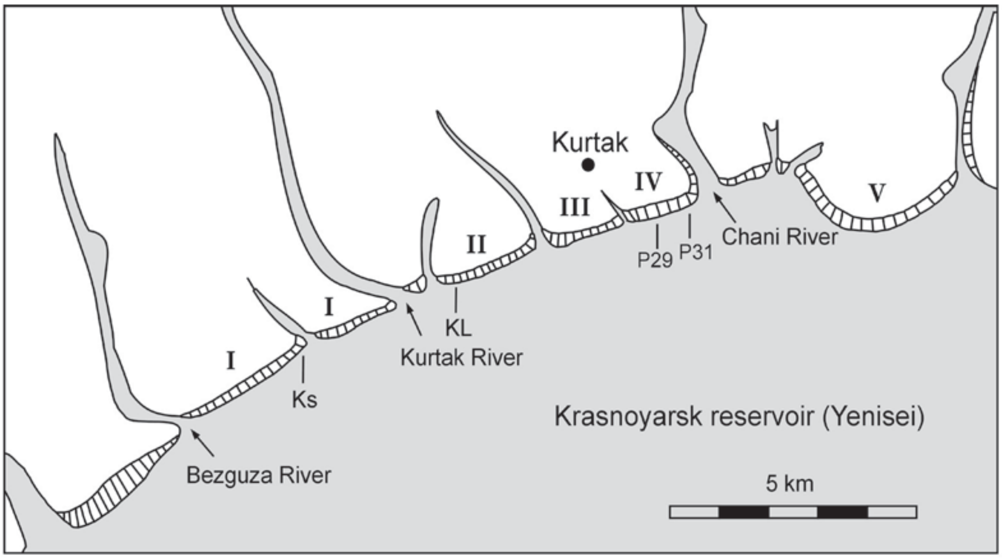


Fig. 1: Map of the Upper Yenisei Basin south of Krasnoyarsk, with location of the Kurtak region.
Fig. 1 : Carte du bassin supérieur de l'Inéiséi au sud de Krasnoyarsk, avec la région de Kurtak.



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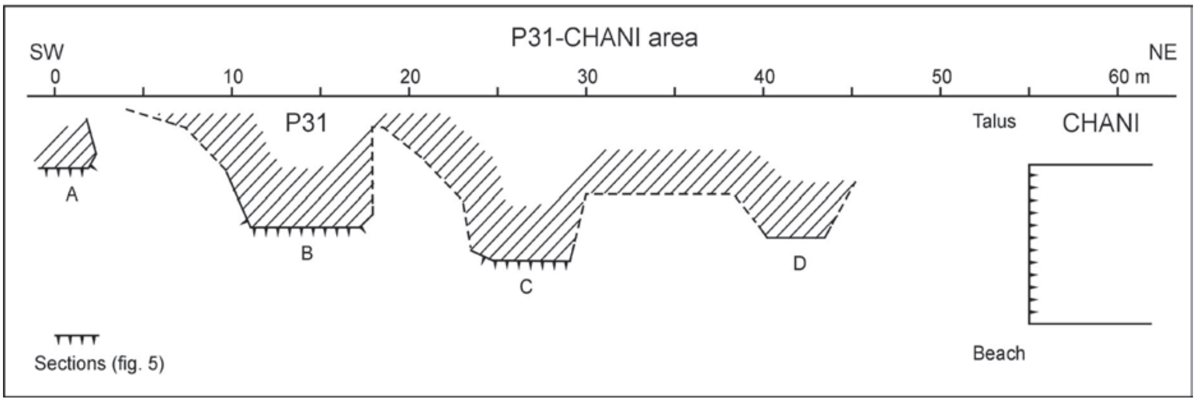

2b

Fig. 2a: Location of the sectors along the Krasnoyarsk reservoir in the suroundings of Kurtak. Legend. I: Trifonovka sector; II: Kurtak sector; III: Sukhoy Log sector; IV: Berezhekovo sector; IV: Ust-Izul sector; Ks: Kashtanka; KL: Kamenny Log.
Fig. 2a : Carte de distribution des secteurs dans la région de Kurtak, avec la position des coupes étudiées.
Légende. I : secteur de Trifonovka ; II : secteur de Kurtak ; III : secteur de Sukhoy Log ; IV : secteur de Berezhekovo ; V : secteur de Ust-Izul ; Ks : Kashtanka ; KL : Kamenny Log.
Fig. 2b: Position of the sections in the P31-Chani area at the north-eastern edge of the Berezhekovo sector.
Fig. 2b : Position des coupes dans l'aire de P31-Chani à l'extrémité nord-est du secteur de Berezhekovo.

Carboniferous sandstones, include a thin alluvial series covered by an atypical loess. The Berezhekovo sector extends over 2 km between the Kurtak village and the Chani River; it shows the most complete Middle and Late Pleistocene loess succession which reaches a thickness of nearly 40 m in the central part of the sector. In the Ust-Izul sector located north-east of the bay of Chani, the Pleistocene succession consists of ca 20 m of loess, alluvial and colluvial deposits of various ages.

3.2 - THE LATE PLEISTOCENE SUCCESSION

The Late Pleistocene loess cover of the Kurtak region has been subdivided in five distinct units (a-e), using the pedosedimentary signature of the deposits recorded in the Kurtak and Berezhekovo sectors (Drozdov *et al.*, 1990; Arkhipov *et al.*, 1992; Derevianko *et al.*, 1992); in the latter sector sections were numbered P1 to P31 from south-west to north-east (fig. 3).

a) The first unit named Kamenny Log Soil is most often preserved on top of the Middle Pleistocene loess cover (Berezhekovo Loess); it shows characteristics of a Siberian chernozem (Zykina, 1999), similar to the surface soil, and has been ascribed to the Kazan Interglacial equivalent to the last interglacial (MIS 5e) in the regional chronostratigraphic system (Derevianko *et al.*, 1992; Velichko, 1992; Drozdov *et al.*, 1999).

b) The Sukhoy Log Pedocomplex, ascribed to the MIS 5d - 5a time period, records the beginning of the Murukta Stage. It consists of a ca 3 m thick colluviated loess-like unit with several soil horizons ranging from chernozem to brown boreal soil.

c) The Chaninsky Loess is represented by ca 10 m of laminated pale yellowish sandy loess, partially redeposited, interbedded with several greyish horizons. It encompasses the lower half of the Late Pleistocene loess cover and records the full development of the Murukta Stage (MIS 4).

d) The Kurtak Pedocomplex is present almost everywhere in the middle of the Late Pleistocene loess cover; it consists of loess-like deposits with a thickness of ca 2 m including two sets of humiferous horizons disturbed by solifluction. Locally two generations of ice wedge pseudomorphs are associated with this unit; the first

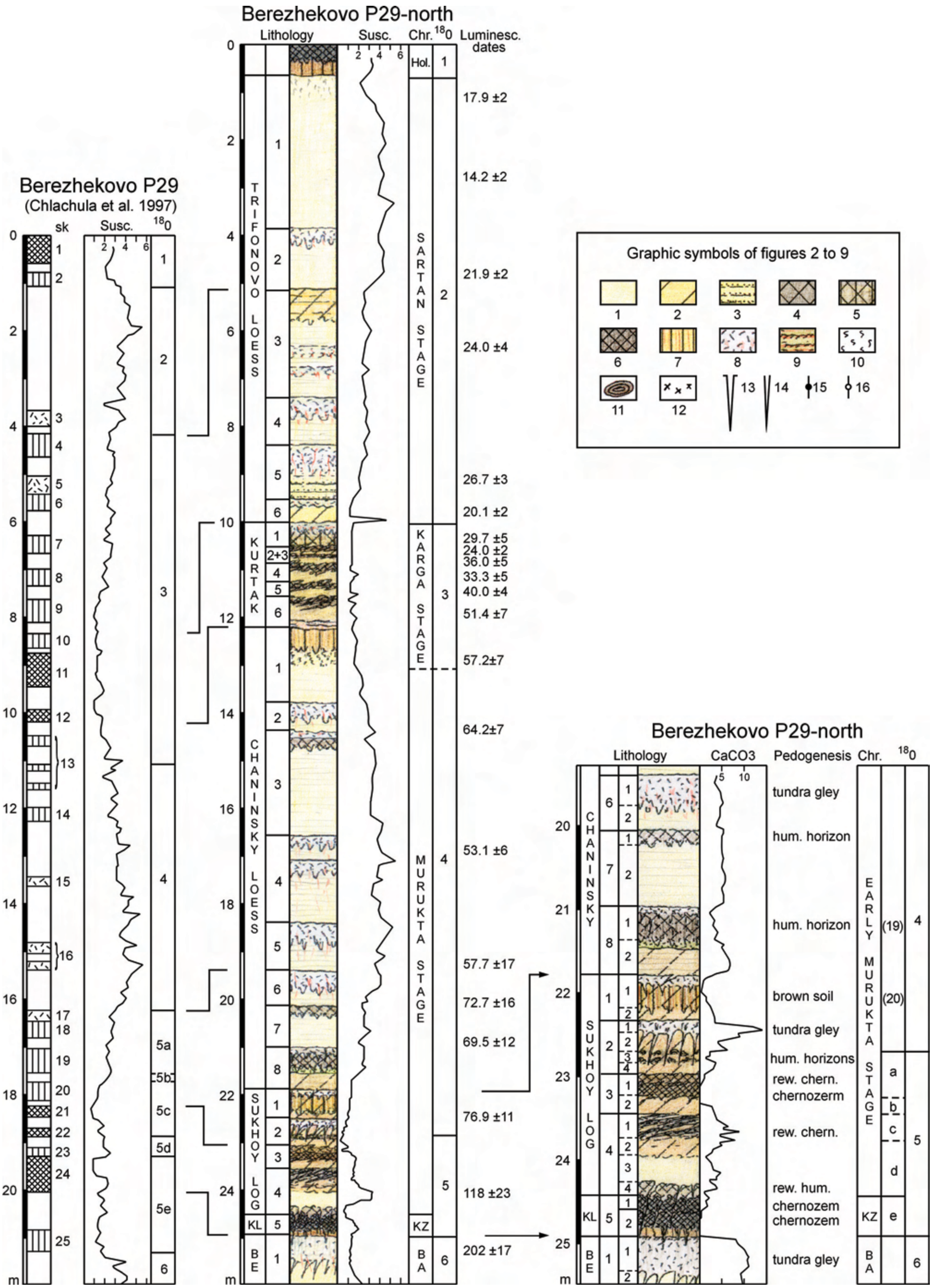

Fig. 3: The Late Pleistocene loess succession in the central part of Berezhekovo sector, at section P29 (left) and at section P29-north (middle and right). Luminescence dates are from Zander *et al*. (2003).
Graphic symbols. 1: loess; 2: light brown loess-like silt; 3: sand; 4: humiferous loess-like silt; 5: bioturbated weak humiferous horizon; 6: humiferous horizon; 7: brown boreal soil (B horizon); 8: bleached horizon (tundra gley); 9: iron staining; 10: secondary carbonates; 11: wood remains; 12: charcoal; 13: ice wedge pseudomorph; 14: frost wedge: 15: Groningen radiocarbon date (GrN); 16: Novosibirsk radiocarbon date (SOAN).

one is located between the two sets of humiferous horizons, while the second one occurs on top of the pedocomplex. The upper generation has been dated by ^{14}C between 24,890 and 23,470 BP at the Kashtanka site in the northern part of the Trifonovka sector (Svezhentsev *et al.*, 1992), while the first generation is dated older than 30,000 BP (Drozdov *et al.*, 1990). According to its position in the sequence, the Kurtak Pedocomplex belongs to the Karga Stage (MIS 3), the lower generation of ice wedge pseudomorphs recording the Zighan-Konoshchel cold phase which occurs in between the Early Karga and the Lipa-Novosolevo warm episodes (Volkov and Orlova, 2000; Zykin *et al.*, 2000).

e) The upper loess cover named Trifonovo Loess follows the present-day topography and records the Sartan Stage (MIS 2). It reaches a thickness of ca 10 m and consists mainly of laminated sandy loess partly redeposited which is interbedded with several greyish horizons; towards the top it changes into a whitish dusty homogenous deposit considered as typical loess.

During the last decade, complementary studies focusing on pedostratigraphy, palaeomagnetism and chronology were performed by several international teams (Chlachula *et al.*, 1997; Chlachula, 1999, 2003; Damblon *et al.*, 1996; Drozdov *et al.*, 1999; Zhu *et al.*, 2003; Zykina, 1999; Zander *et al.*, 2003). The P29 section opened in 1993 by J. Chlachula in the central part of the Berezhekovo sector provided a reference pedosedimentary record for the Late Pleistocene loess (fig. 3, left). This record encompassing a recurrent succession of pedological horizons of brunisolic type (Chlachula *et al.*, 1997) was later integrated in the regional context of southern Central Siberia (Chlachula, 1999; 2003). The P29 section also revealed a particular aspect of the loess of Kurtak, as its magnetic susceptibility signal appeared to be reversed in comparison with the loess of China and Central Asia. Such an inversion is related to the sandy character of the aeolian input mainly originated from the alluvial plain of the Yenisei River (Chlachula *et al.*, 1997; Zhu *et al.*, 2003).

From 1993 to 1998 several sections of the main sectors of the Kurtak region were studied by the Laboratory of Archaeology and Palaeogeography (Krasnoyarsk) in co-operation with Belgian teams. The purpose of these studies was to control the lateral continuity of the deposits in order to ensure an optimal restitution of the Late Pleistocene sequence. A new 26 m thick loess succession was recorded in the central part of the Berezhekovo sector north of the P29 section (fig. 3, middle). Although the pedosedimentary succession of this new section is slightly different from the one described at P29 by Chlachula *et al.* (1997), the magnetic susceptibility signal measured in Belgium in a Kappabridge KLY-1 on a set of 188 samples (Hus, unpublished), shows a signature similar to the P29 curve.

In addition, at P29-north the Kamenny Log Soil and the Sukhoy Log Pedocomplex provided a high-resolution pedostratigraphic record preserved in a local depression (fig. 3, right). In particular, the Kamenny Log Soil, which resembles the present-day leached chernozem, shows a double A1 horizon (subunits 5-1 and 5-2) with ground veins at the base and frost wedges on top. The overlying Sukhoy Log Pedocomplex starts with a thin layer of humiferous colluvium (4-4) followed by a distinct aeolian sandy silt (4-3) which is surmounted by two chernozem-like soils developed on loamy colluvium: the lower one is strongly disrupted by creep (4-1), while the upper one with a distinct leached horizon, is preserved *in situ* (3-1 and 3-2). The latter soil is overlain by ca 1 m of loamy deposits which show two thin humiferous layers in the lower part (2-3), a polygonal row of cracks related to deep seasonal frost in the middle part (2-1) and a strongly bioturbated brown boreal soil (1-1) capping the Sukhoy Log Pedocomplex. Consequently, this high-resolution record leads to a more precise chronostratigraphic approach of the pedosedimentary succession. The Kamenny Log Soil and the two chernozem-like soils of the Sukhoy Log Pedocomplex correspond to MIS 5e, 5c and 5a, respectively. The upper part of the pedocomplex, including the bioturbated brown boreal soil (1-1), probably represents the beginning of MIS 4, together with the two humiferous horizons of decreasing intensity present in the lower part of the Chaninsky Loess (subunits 8-1 and 7-1).

The section P29-north also confirms the complex pedosedimentary succession of the Chaninsky and Trifonovo loess units, mainly related to the occurrence of several greyish horizons with rather abundant iron staining (fig. 3, middle). Their interpretation is still being discussed; although some greyish layers are undoubtedly related to lateral sediment input, in most cases they show evidence of pedological processes (Zhu *et al.*, 2003). These horizons are similar to the tundra gley horizons known from the loess of NW Europe (Haesaerts and Van Vliet-Lanoë, 1981; Antoine *et al.*, 2002) and Central Europe (Klima, 1995; Haesaerts *et al.*, 2003) which record permafrost development in rather humid conditions.

The chronology of the Kurtak sequence has been improved recently by a series of luminescence dates

Fig. 3: Continued. Abbreviations. BE: Berezhekovo Loess; KL: Kamenny Log Soil; CH: Chaninsky Loess; TCH: Tcherniakovsky Soil; KP: Kurtak Pedocomplex; CB: Chani Bay Complex; TR: Trifonovo Loess; BA: Bakhtinsky Stage; KZ: Kazan Interglacial; MU: Murukta Stage; KA: Karga Stage; SA: Sartan Stage; Hol: Holocene; Susc: magnetic susceptibility; rew. chern.: reworked chernozem; Chr: chronostratigraphy; 18O: marine oxygene isotope stage; TG: tundra gley; H: humiferous pedogenesis.

Fig. 3 : Succession loessique du Pleistocène supérieur dans la partie centrale du secteur de Berezhekovo, section P29 (à gauche) et section P29-nord (au centre). Les dates en luminescence sont de Zander et al. (2003).

Symboles graphiques. 1 : loess ; 2 : limon loessique brun clair ; 3 : sable ; 4 : limon loessique humifère ; 5 : horizon faiblement humifère bioturbé ; 6 : horizon humifère ; 7 : sol brun boréal (horizon B) ; 8 : horizon déferrifié (gley de toundra) ; 9 : hydroxydes de fer ; 10 : carbonates secondaires ; 11 : restes de bois ; 12 : charbons de bois ; 13 : pseudomorphose de coin de glace ; 14 : fente de gel ; 15 : date radiocarbone de Groningen (GrN) ; 16 : date radiocarbone de Novosibirsk (SOAN).

Abréviations. BE : Berezhekovo Loess ; KL : Sol de Kamenny Log ; CH : Chani Loess ; TCH : Sol de Tcherniakovsky ; KP : Pédocomplexe de Kurtak ; CB : Complexe de Chani Bay ; TR : Trifonovo Loess ; BA : Stade de Bakhtinsky ; KZ : Interglaciaire de Kazan ; MU : Stade de Murukta ; KA : Stade de Karga ; SA : Stade de Sartan ; Hol : Holocene ; Susc : susceptibilité magnétique ; rew. Ch : chernozem remanié ; Chr : chronostratigraphie ; ^{18}O : stade isotopique marin ; TG : gley de toundra ; H : pédogenèse humifère.

(Zander *et al.*, 2003) for the loess succession of the central part of the Berezhekovo sector close to the section P29-north (fig. 3, middle). These dates show a consistent chronological distribution in agreement with the initial chronostratigraphic framework (Drozdov *et al.*, 1990; Derevianko *et al.*, 1992) and also with the TL stratigraphy established for the Kurtak loess cover by Wansard (1997). Moreover, the luminescence dates of Zander *et al.* (2003) are consistent with the chronostratigraphy of the Kamenny Log Soil and the Sukhoy Log Pedocomplex based on section P29-north (fig. 3, right); they are also in good agreement with the complementary series of radiocarbon dates for the Kurtak Pedocomplex (Damblon *et al.*, 1996) and reinforce its assignment to MIS 3 (Drozdov *et al.*, 1999).

4 - THE KARGA SEQUENCE

From 1994 to 1998 we investigated in detail the lateral distribution of the Kurtak Pedocomplex in the Trifonovka and Kurtak sectors (fig. 4). Also the complementary record P31 was worked out at the north-eastern edge of Berezhekovo sector (figs 2b and 5). At this location, close to the bay of Chani, a ca 6 m thick succession of humiferous silts rich in wood remains is preserved underneath the Trifonovo Loess. This succession is called the Chani Bay Complex, and allows a multidisciplinary approach of an exceptional pedosedimentary and palaeoclimatic record well dated between 42,520 and 25,710 BP.

4.1 - THE KURTAK PEDOCOMPLEX

This pedocomplex ascribed to the Karga Stage (MIS 3) is present everywhere on the plateau in between the Chaninsky and Trifonovo loess units, with a constant thickness of about 2 m (figs 3 and 4). In the Trifonovka and Kurtak sectors the pedocomplex is easy of access over long distances along the beach of the lake and occurs as a succession of loess-like silty layers alternating with humiferous horizons (units KP1 to KP6). Usually the Kurtak Pedocomplex is resting on top of the Chaninsky Loess, which bears a well developed brown boreal soil with B and Cca horizons, named Tcherniakovsky Soil (fig. 4).

In both these sectors and at Berezhekovo as well, the Kurtak Pedocomplex consists of five horizontally layered brownish yellow loess-like silty layers, each one being overlain by a humiferous horizon stretched by solifluction and locally duplicated (units KP2 to KP6). In the Kurtak sector the upper part of unit KP4 shows a gley horizon which presents on top a first generation of ice wedge pseudomorphs. Further, the upper 50 cm of the

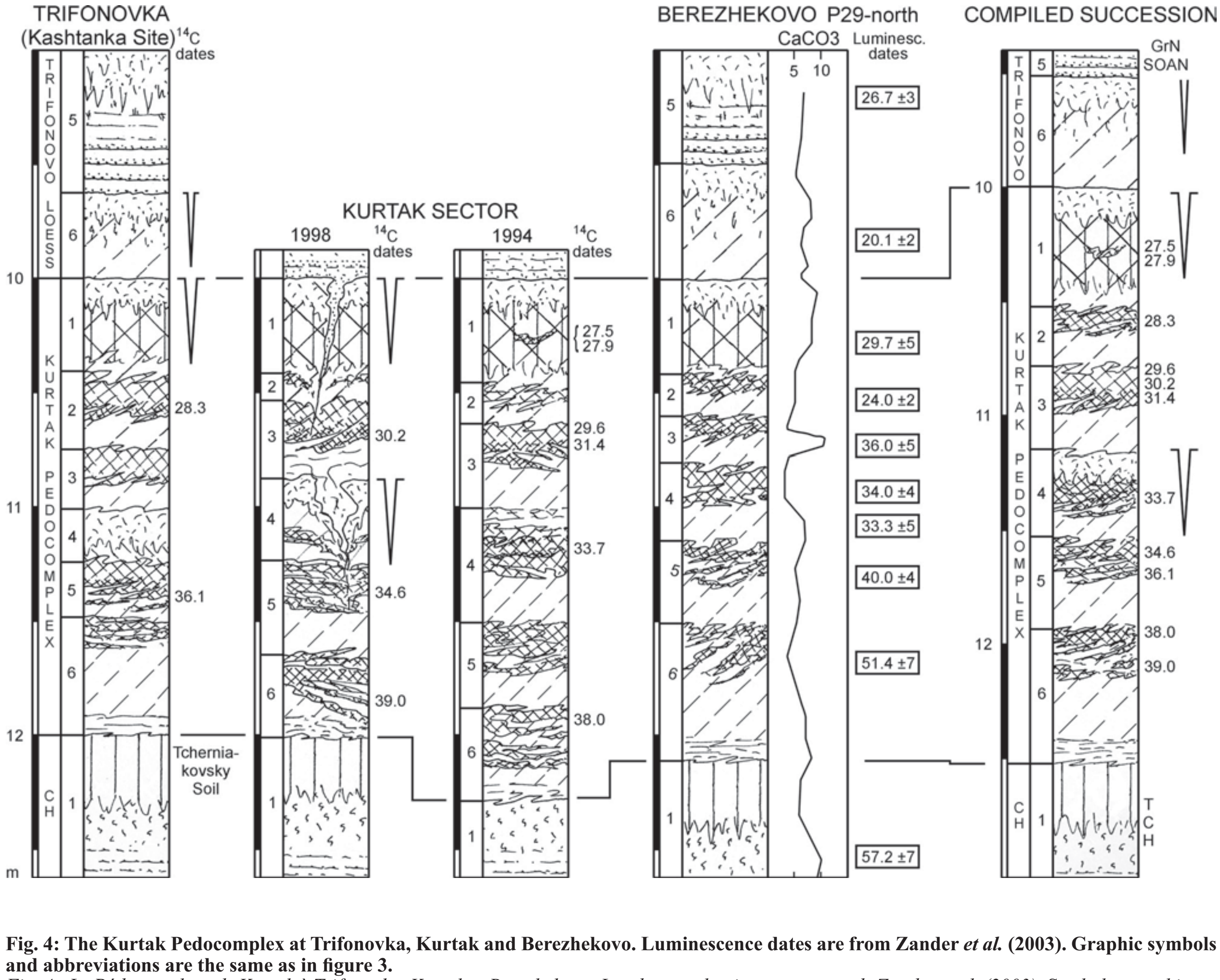

Fig. 4: The Kurtak Pedocomplex at Trifonovka, Kurtak and Berezhekovo. Luminescence dates are from Zander *et al.* (2003). Graphic symbols and abbreviations are the same as in figure 3.

Fig. 4 : Le Pédocomplexe de Kurtak à Trifonovka, Kurtak et Berezhekovo. Les dates en luminescence sont de Zander et al. (2003). Symboles graphiques et abréviations comme dans la figure 3.

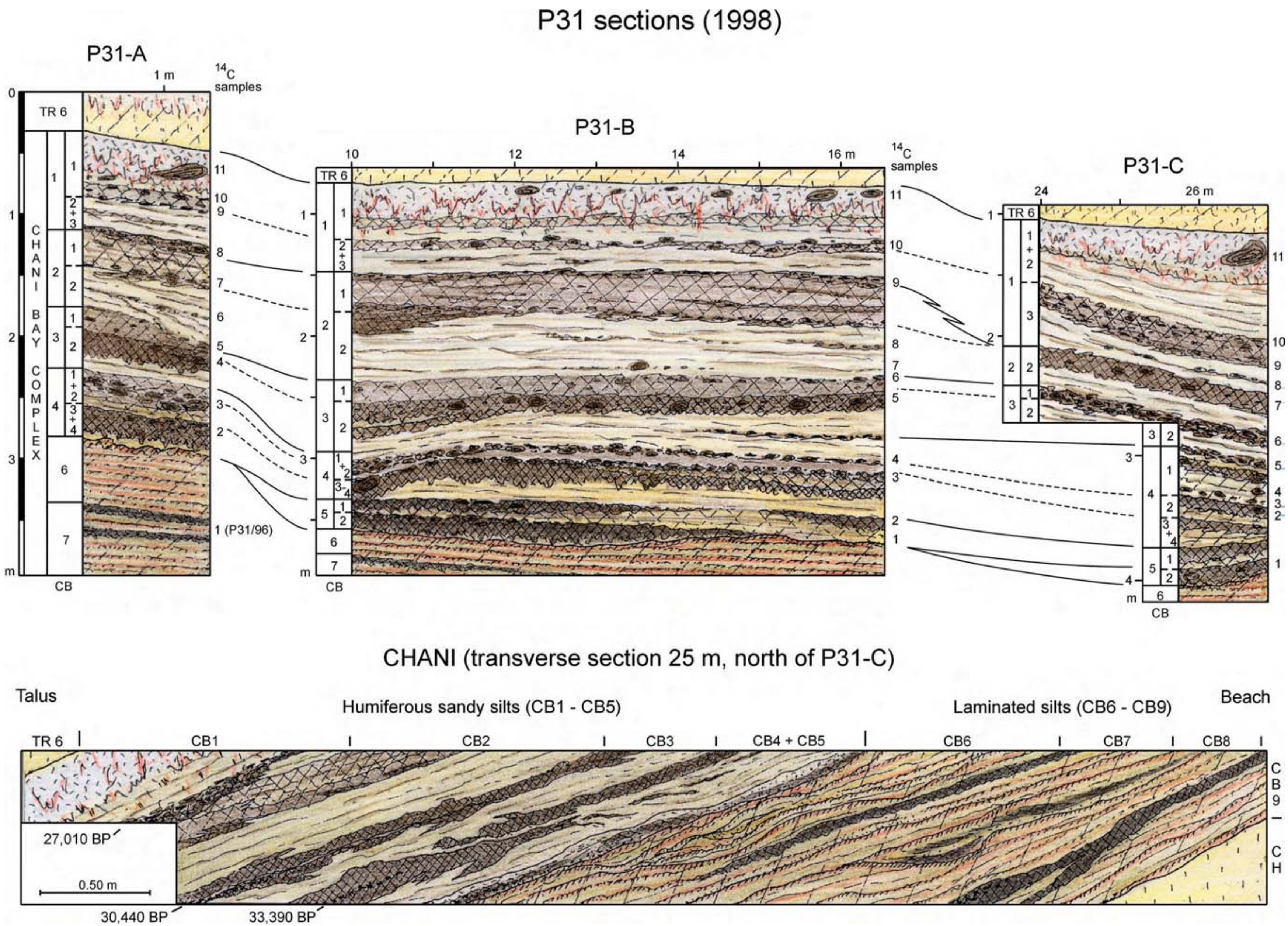

Fig. 5: Stratigraphic succession of the Chani Bay Complex in the P31-Chani area. Graphic symbols and abbreviations are the same as in figure 3.
Fig. 5 : Succession stratigraphique du Complexe de Chani Bay dans l'aire P31-Chani. Symboles graphiques et abréviations comme dans la figure 3.

Kurtak Pedocomplex consists almost everywhere of a greyish brown bioturbated silty horizon (unit KP1) with gleying process in the upper part, locally associated with a second generation of ice wedge pseudomorphs at the interface with the overlying Trifonovo Loess.

In addition, the relative abundance of charcoal clusters in most of the humiferous horizons in the Trifonovka and Kurtak sectors have led to a coherent series of radiocarbon dates ranging from 39,000 to 27,460 BP mainly produced in Groningen (fig. 4; table 1). The distribution of the ages confirms the subdivision of the Kurtak Pedocomplex in six distinct units reproduced in the various sectors. According to this distribution, a charcoal cluster of unit KP1 has provided the dates 27,460 and 27,920 BP, while the humiferous horizons of the subjacent units were dated on charcoal respectively 28,300 BP (KP2), 29,580, 30,200 and 31,410 BP (KP3), 33,740 BP (KP4), 34,600 and 36,100 BP (KP5), 38,000 and 39,000 BP (KP6).

Site	Lithostr. KP	n° lab.	^{14}C age ± 1 σ (BP)	Material
KL	1	SOAN-3276	27,460 ± 230	charcoal
KL	1	GrN-21895	27,920 ± 260	*Picea* ch.
Ka	2	GrN-24481	28,320 ± 190	*Larix* ch.
KL	3	GrN-21896	29,580 + 400 - 460	*Picea* ch.
KL	3	GrA-13286	30,190 ± 350	*Picea* ch.
KL	3	SOAN-3275	31,410 ± 465	charcoal
KL	4	GrN-21358	33,740 + 500 - 480	*Picea* ch.
KL	5	GrN-24478	34,570 + 1150 - 1000	*Picea* ch.
Ka	5	GrN-24482	36,130 ± 310	*Salix* ch.
KL	6	GrA-9246	38,000 + 4,200 - 2,800	*Picea* ch.
KL	6	GrN-24479	39,020 + 710 - 650	*Picea* ch.

Table 1: Radiocarbon dates from the Kurtak Pedocomplex obtained since 1994 in the laboratories at Groningen (GrN and GrA) and Novosibirsk (SOAN). KL: Kamenny Log (Kurtak sector), Ks: Kashtanka (Trifonovka sector).
Tab. 1 : Dates ^{14}C du Pédocomplexe de Kurtak obtenues depuis 1994 à Groningen (GrN et GrA) et Novosibirsk (SOAN). KL : Kamenny Log (secteur de Kurtak), Ks : Kashtanka (secteur de Trifonovka).

4.2 - THE CHANI BAY COMPLEX

From the centre of the Berezhekovo sector, the Kurtak Pedocomplex extends laterally nearly 1 km to the north-east; then, following the slope of the topography, it passes south-west of P31 to a set of ca 4 m thick humiferous sandy silt deposits with abundant wood remains, overlying ca 2 m of laminated silt. These deposits named Chani Bay Complex are developed over a distance of 100 m at the foot of the loess talus that limits the bay of Chani, and fill a broad depression intersecting the Chaninsky Loess (figs 2b and 5).

The sections opened in 1993 and 1994 at Chani and at P31 demonstrated the complexity of the humiferous deposits and the strong lateral variability of the layers rich in wood remains. This complicated situation caused originally chronological discrepancies in the first set of radiocarbon dates produced in Groningen (GrN and GrA), Novosibirsk (SOAN) and Alberta (AECV) on material supposed to be collected from the same horizons (table 2). In order to avoid such uncertainties, the sections P31-A, P31-B and P31-C were opened in 1998 in between the southern side of the depression and Chani (figs 2b and 5). This enabled lateral control of the stratigraphy and the construction of a pedosedimentary sequence of almost 6 m thick subdivided into nine distinct units (CB1 to CB9), directly subjacent to unit 6 of the Trifonovo Loess.

The abundance of wood remains preserved in units CB1 to CB5 led to a systematic sampling of wood material positioned exactly in the stratigraphy of the complementary sections P31-A, P31-B and P31-C, for cross-dating in Groningen and Novosibirsk (*cf.* § 4.3, figs 5 and 6). A series of 62 dates (36 GrN and 26 SOAN) ranging from 25,710 to 36,800 BP was obtained (table 3), which supplement the Groningen dates from 27,010 to 42,520 BP measured earlier (tables 2 and 3; Damblon *et al.*, 1996).

4.2.1 - The laminated silts (units CB9 to CB6)

In the sections open at P31-Chani, the first part of the Chani Bay Complex consists of ca 2 m of laminated greenish yellow silts with abundant iron staining. These deposits, dipping towards the north, are filling the large depression dug in the Chaninsky Loess at the edge of the transverse Chani section (fig. 5). They show three humiferous horizons locally duplicated (units CB9, CB8 and CB7), the upper one being dated 42,520 BP in 1996 on charcoal from P31 (table 3).

Groningen dates			
Subunit	m	n° Lab.	14C age ± 1σ (BP)
1. 2	w	GrN-20867	28,040 ± 170
-	-	-	-
3. 1	w	GrN-20868	30,370 ± 190
4. 1	w	GrN-20869	31,880 ± 350
4. 2	w	GrN-20871	32,870 ± 275
5	ch	GrN-20870	34,260 ± 310

Novosibirsk and Alberta dates			
Subunit	m	n° Lab.	14C age ± 1σ (BP)
1.2	w	SOAN-3272	26,925 ± 265
2.2 ?	w	SOAN-3273	29,010 ± 325
-		-	-
-		-	-
?	w	SOAN-3154	30,385 ± 275
?	w	AECV-1938c	30,400 ± 700
?	w	SOAN-3274	32,450 ± 360

Table 2: Table of radiocarbon dates on wood fragments collected in 1993 and 1994 in the Chani Bay Complex at P31 (w: wood; ch: charcoal).
Tab. 2 : Dates ^{14}C sur fragments de bois collectés en 1993 et 1994 au sein du Complexe de Chani Bay à P31 (w : restes de bois ; ch : charbon de bois).

S.c.	n°	Lithostr.	Material	*n° lab. Gron.*	^{14}C age ± 1σ (BP)	Material	*n° lab. Novos.*	^{14}C age ± 1σ (BP)
		P 31 / A						
a	11	1.1	*Picea* w.	*GrN-24182*	25,980 ± 180	*Picea* w.	*SOAN-3862*	26,190 ± 170
c	10	1.1	*Picea* w.	*GrN-24181*	26,150 ± 160	-	*SOAN-3861*	26,260 ± 170
c	9	1.1	*Picea* w.	*GrN-24180*	26,300 ± 160	-	*SOAN-3860*	26,430 ± 355
b	8	1.3	*Picea w.*	*GrN-24472*	28,150 ± 170	-	*SOAN-3859*	27,700 ± 150
c	7	2.1	*Picea* w.	*GrN-24179*	28,830 ± 210	-	-	-
b	6	2.2	*Picea* w.	*GrN-24471*	29,330 ± 390	-	-	-
b	5	3.1	*Picea* w.	*GrN-24470*	30,550 ± 180	-	*SOAN-3857*	29,610 ± 245
b	4	3.2	*Picea* w.	*GrN-24469*	30,800 ± 150	-	*SOAN-3856*	30,380 ± 360
b	3	4.2	*Picea* w.	*GrN-24468*	32,160 ± 190	-	*SOAN-3855*	31,900 ± 295
b	3	4.2	*Picea* w.	*GrN-25034*	33,200 ± 360	-	-	-
b	2	4.3	*Larix/Picea* w.	*GrN-24467*	32,110 ± 40	-	*SOAN-3274*	32,450 ± 360
b	2	4.3	*Larix/Picea* w.	*GrN-25033*	33,250 ± 310	-	-	-
d	1(96)	7	*Picea* ch.	*GrA-6866*	42,520 + 730 -670	-	-	-
		P 31 / B						
a	11	1.1	*Picea* w.	*GrN-24193*	26,020 ± 180	*Picea* w.	*SOAN-3874*	25,710 ± 455
b	10	1.2	*Picea* w.	*GrN-24192*	26,700 ± 200	-	*SOAN-3873*	27,000 ± 270
b	9	2.1	*Picea* w.	*GrN-24,191*	28,530 ± 200	-	*SOAN-3872*	28,630 ± 525
c	8	2.2	*Picea* w.	*GrN-24190*	29,140 ± 210	-	*SOAN-3871*	29,000 ± 540
a	7	2.2	*Picea* w.	*GrN-24188*	30,000 ± 280	*Picea* w.	*SOAN-3870*	30,020 ± 305
b	6	3.1	*Picea* w.	*GrN-24189*	30,210 ± 260	-	-	-
b	5	3.2	*Picea* w.	-	-	-	*SOAN-3868*	30,450 ± 650
a	5	3.2	*Picea* w.	*GrN-24187*	30,730 ± 300	*Picea* w.	*SOAN-3869*	30,640 ± 395
b	4	4.2	*Picea* w.	*GrN-24186*	32,880 ± 340	-	*SOAN-3865*	31,750 ± 270
b	4	4.2	*Picea* w.	-	-	-	*SOAN-3867*	31,850 ± 340
b	4	4.2	*Picea* w.	-	-	-	*SOAN-3866*	32,000 ± 350
a	3	4.3	*Picea* w.	*GrN-24185*	33,580 ± 360	*Picea* w.	*SOAN-3863*	32,960 ± 455
b	3	4.3	*Picea* w.	-	-	-	*SOAN-3864*	32,720 ± 575
b	2	5.1	*Picea* w.	*GrN-24184*	34,230 ± 300	-	-	-
b	2	5.1	*Picea* w.	*GrN-25032*	34,500 ± 470	-	-	-
b	1	5.2	*Picea* w.	*GrN-24183*	36,000 ± 360	-	-	-
b	1	5.2	*Larix* w.	*GrN-25031*	36,300 ± 500	-	-	-
		P 31 / C						
a	11	1.1	*Picea* w.	*GrN-24199*	26,460 ± 180	*Picea* w.	*SOAN-3880*	26,620 ± 250
c	10	1.3	*Picea* w.	*GrN-24477*	27,690 ± 180	-	-	-
c	9	1.3	*Picea* w.	*GrN-24476*	27,880 ± 160	-	*SOAN-3879*	27,430 ± 340
b	8	1.3	*Picea* w.	*GrN-24475*	27,950 ± 180	-	*SOAN-3878*	28,580 ± 450
b	7	2.2	*Picea* w.	*GrN-24474*	28,900 ± 240	-	-	-
b	6	3.1	*Picea* w.	*GrN-24473*	30,080 ± 180	-	*SOAN-3877*	29,480 ± 300
b	5	3.2	*Picea* w.	*GrN-24198*	31,500 ± 280	-	*SOAN-3876*	30,950 ± 430
b	4	4.1	*Picea* w.	*GrN-24197*	32,140 ± 320	-	-	-
b	3	4.2	*Picea* w.	*GrN-24196*	32,130 ± 350	-	*SOAN-3875*	32,990 ± 300
b	2	4.2	*Picea* w.	*GrN-24195*	32,500 ± 200	-	-	-
b	1	5.2	*Picea* w.	*GrN-25035*	36,800 ± 470	-	-	-
		Chani 94						
c		CB1	*Picea* w.	*GrN-20872*	27,010 ± 170		-	-
c		CB3	*Picea* ch.	*GrA-6745*	30,440 ± 220		-	-
c		CB4	*Picea* ch.	*GrN-21357*	33,390 + 580 -540		-	-

Table 3: Table of radiocarbon dates for the Chani Bay Complex sampled in 1998 (s.c.: sampling categories).
Tab. 3 : Dates radiocarbone du Complexe de Chani Bay prélevé en 1998 (s.c. : types d'échantillon).

4.2.2 - The humiferous sandy silts (units CB5 to CB1)

The main part of the Chani Bay Complex encompasses ca 4 m of yellowish grey silty deposits subdivided in five units; it includes several humiferous horizons with abundant wood remains dated between 25,710 and 36,800 BP (figs 5 and 6; table 3).

Unit CB5

This unit which truncates the top of the laminated silts is well developed in sections P31-B and P31-C; it shows two dark brown humiferous horizons (subunits 5-2 and 5-1) separated by ca 15 cm of yellowish grey sandy silt. Wood remains from both horizons were dated respectively 34,500 and 34,230 BP (subunit 5-1) and 36,800 to 36,000 BP (subunit 5-2). In the other sections unit CB5 is hardly represented, except in the P31/93-94 section where the lower humiferous horizon was dated to 34,260 BP on charcoal (table 2).

Unit CB4

This unit records a complex succession, starting with ca 30 cm of yellowish grey sandy silt with a well developed humiferous horizon on top, locally duplicated at P31-B (subunits 4-4 and 4-3). Wood fragments from these horizons have provided six dates ranging from 33,580 to 32,110 BP, most of them centered around 33,000 BP. At P31-A and P31-B the humiferous horizons 4-4 and 4-3 are capped by ca 30 cm of brown grey silt (subunits 4-2 and 4-1) incorporating a significant concentration of wood fragments dated between 33,200 and 31,750 BP. At P31-C this wood concentration is grading into a small

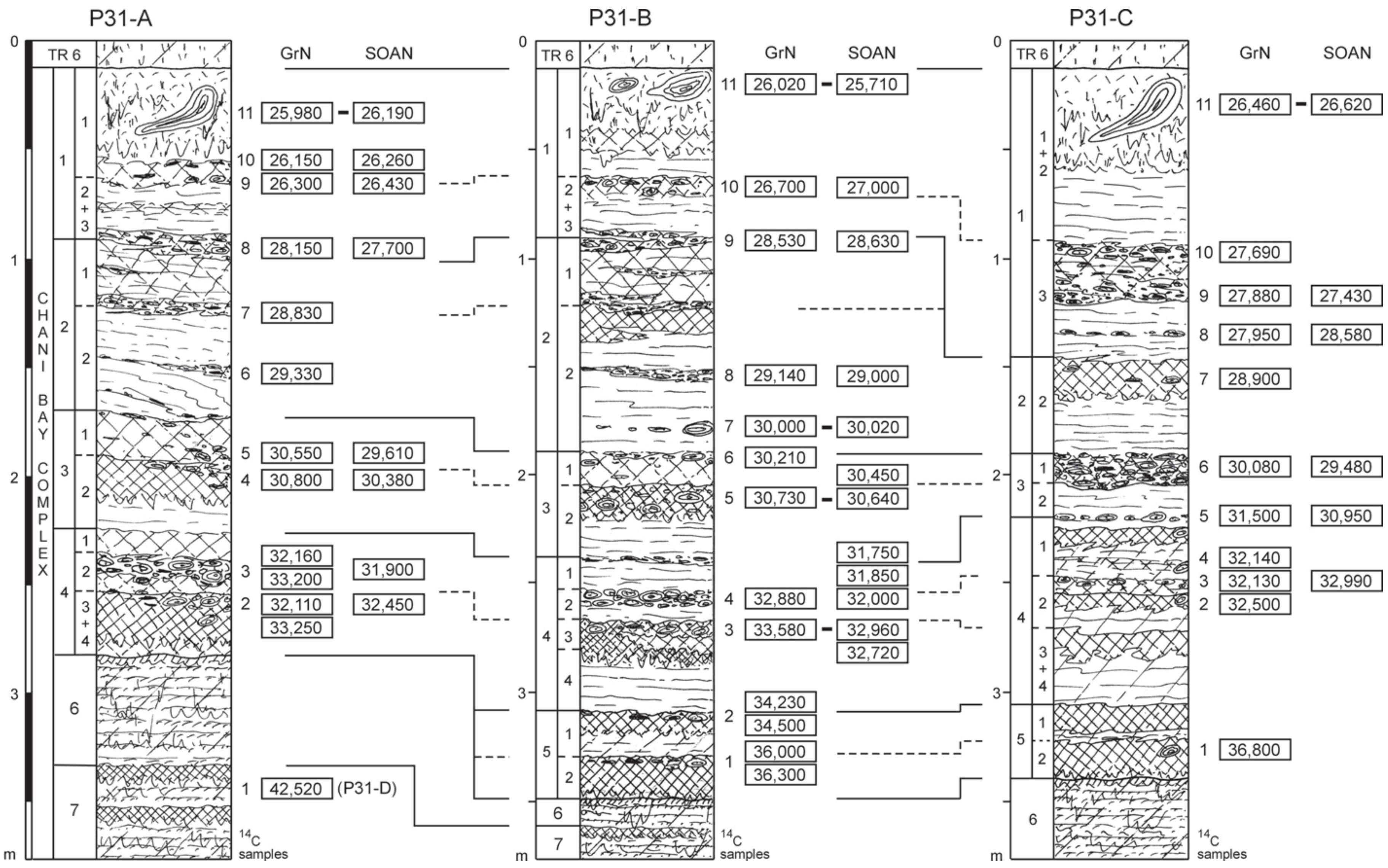

Fig. 6: Distribution of the radiocarbon dates in the sections P31-A, P31-B and P31-C.
Fig. 6 : Distribution des dates radiocarbone dans les coupes P31-A, P31-B et P31-C.

humiferous horizon (4-2) followed by brownish grey silt (4-1), dated between 32,990 and 32,130 BP capped by a second humiferous horizon surmountedly wood remains dated 31,500 and 30,950 BP; this second horizon probably corresponds to the top of subunit 4-1 at P31-B which contains a thin layer of wood remains in a similar position as these dated 31,880 BP in the P31-94-section (table 2).

Unit CB3

The lower part of unit CB3 is recorded in most of the sections by ca 30 cm of yellowish grey laminated sandy silt bearing a well developed humiferous horizon (subunit 3-2) with abundant wood fragments dated between 30,800 and 30,380 BP at P31-A and P31-B. This soil is often covered by a slightly humiferous deposit (subunit 3-1) containing rather abundant wood remains well dated between 30,550 and 29,610 BP. At P31-C subunit 3-1 which occurs as a concentration of wood remains almost similar to the wood concentration of subunit 4-2, was dated 30,080 and 29,480 BP.

Unit CB2

This unit is to some extent a duplication of CB3; the lower part shows ca 50 cm of yellowish grey sandy silt (subunit 2-2) with lenses of wood remains dated in succession between 30,020 and 29,000 BP. At P31-B and P31-C the silt is passing upwards into a grey-brown humiferous horizon dated 28,900 BP. At P31-B this horizon is capped by light humiferous sandy silt (subunit 2-1) with several lenses of wood remains dated 28,630 and 28,530 BP.

Unit CB1

The upper unit of the Chani Bay Complex consists of three subunits characterised by a slightly oblique geometry towards the north-east. At the P31-C section the yellowish grey sandy silt of subunit 1-3 truncates unit CB2 and develops a small gully filled with light humiferous deposits rich in wood remains, the whole subunit being dated between 28,580 and 27,690 BP. The following subunit 1-2 consists of light grey sandy silt containing a second generation of wood remains dated 27,000 and 26,700 BP at P31-B and 27,010 BP in the upper part of the transverse section at Chani (fig. 5). Subunit 1-2 is capped by a light grey sandy silt on top of which a thick gley horizon with abundant iron staining along rootcasts had developed (subunit 1-1). In the lower part of this subunit wood remains are dated between 26,430 and 26,150 BP, while conifer stumps present in the gley horizon are dated between 26,620 and 25,710 BP.

4.3 - RADIOCARBON STRATEGY

4.3.1 - Distribution of the dates and nature of the material

A unique dataset of about 100 radiocarbon dates is currently available for the middle pleniglacial deposits of Kurtak. The series of dates can be divided into four distinct groups, as indicated below. Note that three techniques for measuring ^{14}C are compared here: Gas Proportional Counting and Liquid Scintillation Counting, which are both conventional (radiometry, gram size samples) and Accelerator Mass Spectrometry (AMS, milligram size samples). Groningen employs two methods: conventional (laboratory code GrN) and AMS (code GrA); Alberta (code AECV), Novosibirsk (code SOAN), and other Russian laboratories are conventional.

- A first group consists of ten dates of unequal quality carried out before 1993 in various Russian laboratories (Drozdov *et al.*, 1990, 1999; Svezhentsev *et al.*, 1992); as the stratigraphic positioning of most of these dates is poorly documented, they are not further considered here.
- A second group consists of eleven coherent dates obtained since 1994 in Groningen and partly in Novosibirsk for units KP1 to KP6 of the Kurtak Pedocomplex in the sectors of Trifonovka and Kurtak (table 1). They are obtained from high quality charcoal clusters, mostly from humus bearing horizons stretched by solifluction.
- A third group comprises ten dates carried out mainly on wood fragments collected in 1993 and 1994 in the Chani Bay Complex at P31 (table 2). Among them, the five dates of Groningen form a coherent dataset; however, they show some differences with the dates obtained in Novosibirsk and in Alberta (Canada) for samples supposedly equivalent but taken separately. This situation led to a thorough stratigraphic control of the samples collected later which have provided the fourth group of dates.

The fourth group consists of a series of sixty-six dates produced jointly in Groningen and Novosibirsk, mainly on non carbonised wood fragments of conifer. The samples were obtained from the Chani Bay Complex in profiles P31-A, P31-B and P31-C and in the transverse profile at Chani (table 3). The sampling covers the main part of units 1 to 5 of the Chani Bay Complex (figs 5 and 6). It was carried out jointly and in a systematic way, because the good quality of the material enabled direct comparison of results obtained from the two laboratories. From this point of view, three types of double sampling were carried out, depending on the material available for cross-dating in Groningen and Novosibirsk (*cf.* sampling categories, table 3). A first series of samples (a) consists of single wood fragments of large size split in two equal parts; a second series of samples (b) consists each time of two distinct wood elements lying flat in the same layer; a third type of sampling (c) joins together several elements of small size extracted from the same layer.

4.3.2 - Comparison of the GrN and SOAN dates

The three series of samples taken simultaneously for the profiles P31-A, P31-B and P31-C yields a total of 62 dates, 36 measured in Groningen (GrN and GrA) and 26 in Novosibirsk (SOAN). The agreement between the dates resulting from the two laboratories is very good, in particular for the six duplicate dates carried out for the wood samples split in two parts (fig. 6, table 3). This agreement is obvious for the uppermost samples 11 of the three profiles dated around 26,000 BP and for the samples 7 and 5 of profile P31-B dated respectively around 30,000 and 30,700 BP. Moreover, the dates 33,580 ±360 (GrN) and 32,960 ±455 (SOAN) for sample 3 of P31-B are also consistent, taking the measurement errors into account.

The good agreement between the dates provided by the two laboratories is mainly due to the quality of the wood material, the excellent preservation state of wood and the well defined stratigraphic positioning of the samples. The results show that the SOAN dates, which cover the period ranging from ca 25,700 to ca 33,000 BP, are as equally useful for the radiocarbon chronology as the GrN dates. Generally these dates make sense only inside each sequence while their accuracy and precision must be considered by comparison with the stratigraphic context. This way, the succession of the groups of dates within profiles P31-A, P31-B and P31-C led to the definition of short events with a time resolution of a few centuries. The good quality and selection of datable material, the intercomparison by 3 independent radiocarbon laboratories (GrN, GrA, SOAN) and a strict stratigraphic control of the sequence guarantee quality assurance of the chronology (van der Plicht and Bruins, 2001).

4.4 - PALAEOBOTANY

4.4.1 - Xylology and anthracology

The plant macroremains were present in two forms (table 4): on the one side non carbonised wood remains (W) were only preserved within the sequence of the Chani Bay Complex and, on the other side, carbonised remains (C) were met in all sections but especially within those of the Kurtak Pedocomplex at Kamenny Log (Kurtak sector) and Kashtanka (Trifonovka sector).

Within the Chani Bay Complex, at P31 and Chani, the wood remains consist of horizontal roots, branches, bark and sometimes of stumps. They belong almost completely to the genus *Picea* (table 4), even if some object shows one or another isolated anatomical character of *Larix*. Moreover, some charred remains of *Picea* needles, showing good visible resin canals, enabled the identification of *Picea obovata* Ledeb, suggesting that the wood remains could belong to this species. Lastly, tissular remains of *Picea* were also represented by stomata and recognisable cross-field wood debris in the pollen slides.

Wood remains identified as *Larix* were found only in two layers of units CB5 and CB4. Remains of *Pinus* from the P31-94 profile, dated to ca 30,000 BP, were identified by the Forest Laboratory of Krasnoyarsk. In addition, charcoal remains were preserved in variable quantities in all the sections, but especially in the Kurtak Pedocomplex (Kurtak and Trifonovka sectors). Charcoal of *Picea* constitutes the main taxon represented either in the form of clusters or more dispersed in the mass of the humiferous horizons of the Kurtak Pedocomplex (table 1). Moreover, charcoal of *Pinus* type *sibirica* was preserved in unit KP4 at Kamenny Log.

The short leaved deciduous trees were represented by charcoal of *Salix* in unit KP5 at Kashtanka as well as in unit CB4 at Chani. *Betula* was also recognised in this unit. Remains of vessels and scalariform plates of the *Betula* type were regularly observed in the pollen slides of almost all samples. No remains of broad-leaved deciduous trees were found in the wood and charcoal assemblages. Finally, it is interesting to note that carbonised culm fragments of Poaceae, identifiable by their tubular structure and the shape of the epiderm cells, were observed in the sections of Kamenny Log and Chani. These remains of grass, present most notably in the soils of the plateau, could be an indication for the proximity of the past steppe environment at Kurtak.

4.4.2 - Palynology

The Palynology column of figure 7 shows a synthesis of the evolution of the vegetation based on about fifty successive pollen spectra obtained from units CB1 to CB7 of the Chani Bay Complex in the P31-Chani area. The position of the spectra in stratigraphy was controlled by the geometry of the layers and is well framed by 67 radiocarbon dates mainly on wood remains which enabled an evolutionary reconstruction of the environment between ca 37,000 and 26,000 BP.

The taxa

The detailed pollen diagram reveals a strongly diversified taxonomic composition of the pollen spectra, especially for the herbaceous taxa (NAP) which include a majority of steppe elements such as Poaceae, *Artemisia* and other Asteraceae, Chenopodiaceae, as well as a part of Cyperaceae. The pollen assemblages contain small proportions of water plants as well as spores of Bryophytes the latter becoming abundant at the top of the sequence.

In contrast, the arboreal taxa (AP) are primarily represented by conifers, mainly *Picea* which largely dominates a great number of spectra. Charred macroremains of needles at Chani point to the species *Picea obovata* Ledeb. Pollen of pine is also abundant and consists of *Pinus* t. *sibirica* and *P*. t. *sylvestris*. *Larix* pollen is present but always in small proportions. Lastly, pollen grains of *Abies*, *Juniperus* and *Ephedra* are scattered except in the top of the sequence where *Juniperus* shows a continuous curve. Among boreal deciduous trees and shrubs, birches are represented by *Betula* t. *alba* and *B*. t. *nana*. Their proximity is also attested by the regular occurrence of vessel debris and scalariform plates of *Betula* type. Pollen grains of *Salix*, *Populus*, *Alnus* and *Alnaster* were observed irregularly and always with small percentages. Pollen of mesophilous broad-leaved deciduous trees was not detected in the whole sequence.

The pollen sequence

The sequence of the Chani Bay Complex is subdivided in 11 local pollen zones (numbered from 0 to 10) determined by the regression and the extension of the *Picea* and *Pinus* pollen curves which largely dominate the arboreal component of the spectra. Pollen zones 1 to 10 are recorded in parallel with the main pedosedimentary events of stratigraphic units CB5 to CB1 dated between 36,800 and 25,710 BP. Pollen zone 0 is recorded in units CB6 and CB7 dated around 42,500 BP and separated from the preceding units by a hiatus of sedimentation (fig. 6).

Each pollen zone begins with a regression phase leading to a minimum of *Picea* (subzone a), followed by a phase of increase with a maximum of *Picea* (subzone b). Pollen subzones (a) correspond to phases of loess deposit, while subzones (b) are recorded in the humiferous horizons or

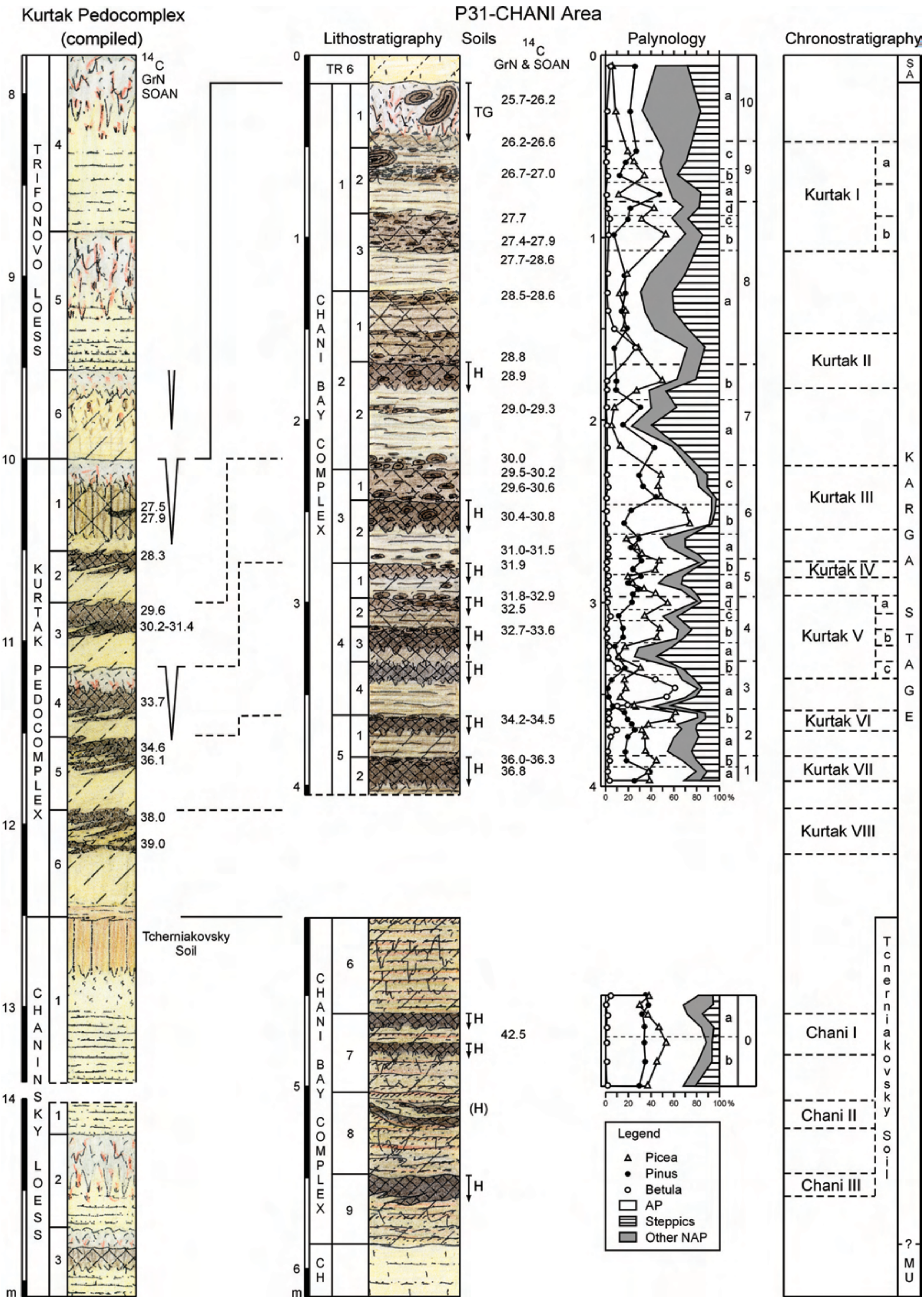

Fig. 7: Kurtak Pedocomplex and Chani Bay Complex: correlative scheme, radiocarbon dates, pollen record and climatic sequence. Graphic symbols and abbreviations are the same as in figure 3.

Fig. 7 : Pédocomplexe de Kurtak et Complexe Chani Bay : schéma corrélatif, dates radiocarbone, enregistrement pollinique et séquence climatique. Symboles graphiques et abréviations comme dans la figure 3.

		Kurtak Pedocomplex							Chani Bay Complex			
		Ku	Trif.	Ku	Ku	Ku	Trif.	Ku		Chani		P 31
Taxa	units	KP1	KP2	KP3	KP4	KP5	KP5	KP6	CB1	CB3	CB4	global
Picea	W	-	-	-	-	-	-	-	W	-	-	W
Picea	C	-	*	**	*	***	*	**	-	***	***	***
Picea obovata	N	-	-	-	3	-	-	-	-	3	-	-
Picea / Larix	C	***	-	-	-	-	-	**	-	-	-	-
Larix / Picea	C	-	-	**	-	-	-	-	-	-	-	-
Larix / Picea	W	-	-	-	-	-	-	-	-	-	-	W
cf. Larix	C	*	***	-	-	*	-	-	-	-	-	1
Pinus t. sibirica	C	-	-	-	***	-	-	-	-	-	-	-
Salix	C	-	-	-	-	-	***	-	-	-	*	-
Betula	C	-	-	-	-	-	-	-	-	-	1	-
Poaceae	C	-	-	-	3	-	-	4	-	-	1	-
Nb fragments		97	509	295	240	262	805	400	1	231	314	37 (W)

Table 4: Charcoal and wood material identified in the Kurtak Pedocomplex and the Chani Bay Complex. Legend. W: wood remains; C: charcoal; N: carbonised needles. For charcoal, 1-4: isolated pieces, *: < 25 %, **: 25-50 %, *: > 50 % of the total. Ku: Kurtak sector (Kamenny Log), Trif.: Trifonovka sector (Kashtanka).**

Tab. 4 : Charbon de bois et restes de bois identifiés (Pédocomplexe de Kurtak et Complexe de Chani Bay).
*Légende. W : restes de bois ; C : charbon de bois ; N : restes carbonisés d'aiguille. Pour les charbons de bois, 1-4 : nombre de pièces isolées ; * : <25 % ; ** : 25-50 % ; *** : > 50 % du total. Ku : secteur de Kurtak (Kamenny Log) ; Trif : secteur de Trifonovka (Kashtanka).*

in the wood accumulations. We note that subzones (c) and (d), which start up the regression phases of *Picea* in pollen zones 6, 8 and 9, appear associated with lateral input incorporating rill-washed wood remains.

In addition, two peaks of *Betula* are marked in subzones (a) of zones 3 and 8 together with a strong regression of *Picea*. The *Pinus* curve, often subordinated to that of *Picea*, develops mainly following a regression of *Picea* in the subzones (a) and manages to exceed it in the upper half of the sequence. This feature in the *Pinus* pollen curve is caused by a relative distance of the populations of pine trees compared to those of spruce.

The distribution and percentage fluctuations of the herbaceous taxa, in particular of the steppic elements, are conversely given by the variations of the *Picea*, *Pinus* or *Betula* percentages. The herbaceous ones show peaks in the non or low humiferous loess-like layers, with maxima in the pollen subzones 3a, 4a, 5a, 6a, and then present a fuller development starting from the pollen subzone 7a which belongs to the stratigraphic subunit 2-2 from which the base was dated to 30,000 BP. The transition from subzone 6c to 7a thus appears as a major shift in the pollen record.

Climatic signature

A specific character of the pollen sequence of the Chani Bay Complex relates to the indigenous character of main pollen associations, a deduction based on several complementary aspects of the record, which plead in favour of the local origin of the pollen of spruce and the proximity of the steppe elements.

One important aspect is the coincidence of the pollen subzones and the stratigraphic subdivisions, the peaks of *Picea* being reached in the soils and the wood accumulations while the maxima of the herbaceous plants appear in the non humiferous loess-like layers. On the other hand, the fact that the curve of *Picea* approaches the curve of the AP also suggests a local origin of the pollen of spruce, which is confirmed by the great abundance of spruce wood remains in units CB1 to CB5. Moreover, the local origin of tree pollen, especially of *Picea*, is also in agreement with the high pollen concentrations correlating to maxima in the arboreal pollen recorded in the three stratigraphic units of the lower half of the sequence, subjacent to subunit 2-2. These maxima can reach values of up to 50,000 grains per gram of sediment. From subunit 3-1, the pollen concentrations decrease significantly to reach a minimum in subunit 1-1. Thus, the variations of the pollen concentrations confirm the environmental shift marked by a greater extension of herbaceous taxa in the sequence from the base of unit CB2.

In addition, the differential distribution of the pollen data argues in favour of a climatic origin of the palynologic events observed. This is obvious for the seven palaeosols, associated with subunits 5-2, 5-1, 4-3, 4-2, 4-1, 3-2 and 2-2, each one recording a local extension of spruce also attested by the occurrence of the wood remains in or at the surface of the soil. Similarly, the wood remains accumulated in the silty subunits 3-1, 2-1, 1-3 and 1-2 come from the immediate vicinity, although they are not exactly in place. This is confirmed by the succession of the radiocarbon dates (decreasing and not reversed) on wood within these subunits. Consequently, all the peaks in the pollen curve of *Picea* are interpreted as the result of a positive climatic oscillation.

The minima in the curve of *Picea* coupled to an extension of the herbaceous steppe elements within the non-humiferous layers derive from negative climatic oscillations. Extension of *Betula*, comprising that of *B.* t. *nana*, in subzones (a) is consistent with a cold climate. In the same way, the extensions of *Pinus* in the upper half of the sequence seem to correspond to a better pollinic expression of the pine trees on behalf of populations adapted better to unfavourable climatic conditions and filling the decreasing production of the spruce trees in regressive phases. Finally, the last pollen zone 10 at the top of the record also includes strong extensions of Cyperaceae and Bryophytes, evoked by the raise of NAP curve in the present diagram, that point to a steppe-tundra vegetation.

5 - THE REGIONAL RECORD

5.1 - THE PEDOSEDIMENTARY SUCCESSION

The stratigraphic data obtained between 1994 and 1998 for the middle part of the Late Pleistocene Kurtak sequence are important for the multidisciplinary investigation of the Chani Bay Complex. This complex is preserved in a lateral depression of the Chani Valley and supplements the sequence of the Kurtak Pedocomplex and the subjacent Tcherniakovsky Soil which developed on the plateau. The connection between both successions was controlled in the north-eastern part of the Berezhekovo sector. It is based on the position of the Tcherniakovsky soil at the top of the Chaninsky Loess, as well as on the lateral continuity of the tundra gley which caps the Kurtak Pedocomplex in the central part of the Berezhekovo sector (unit KP1) and is linked up to the tundra gley of unit CB1 at the top of the Chani Bay Complex (fig. 7). Moreover these two parallel complementary records show similar pedosedimentary dynamics characterised by recurring loess-like input generally followed by humiferous pedogenesis. In particular, units CB1 to CB5 of the Chani Bay Complex prove to be equivalent to the units KP1 to KP5 of the Kurtak Pedocomplex, the synchroneity of the climatic system being implicated by a double coherent series of radiocarbon dates between ca 27,500 and 37,000 BP. The sixth unit of the Kurtak Pedocomplex which dates to ca 39,000 BP on the plateau, corresponds to the hiatus recorded in the P31-Chani area between the base of unit CB5 close to 37,000 BP and the subjacent laminated silts (units CB6 to CB9). Consequently, these deposits with the upper part dated to 42,520 BP in P31 can be placed parallel with the Tcherniakovsky Soil developed at the top of the Chaninsky Loess outside the valley of Chani.

5.2 - PALAEOENVIRONMENT AND CLIMATIC SIGNATURE

The conjunction of the Kurtak Pedocomplex and the Chani Bay Complex leads to a detailed succession of pedosedimentary and climatic events ascribed to the Karga Stage (MIS 3). The regional significance of the climatic signature of the system is further ensured by the good correspondence between the pedosedimentary records of the Kurtak Pedocomplex and the Chani Bay Complex documented by palynology at P31 and by the firm chronology obtained by a consistent set of radiocarbon dates in both records (fig. 7).

Altogether 14 warm climatic episodes are identified in this sequence. Using the Kurtak Pedocomplex as a reference, the warm periods between ca 26,500 and ca 39,000 BP, characterised by extending spruce and humiferous pedogenesis, are labelled Kurtak Ia to Kurtak VIII. Similarly, the humus bearing horizons of the laminated silts (units CB7 to CB9), whose upper part is associated with the pollen zone 0 around 42,500 BP, are referenced to the climatic episodes Chani I to Chani III using the Chaninsky Loess bearing the Tcherniakovsky Soil. Consequently, each warm episode records a period of soil surface stabilisation under continuous and relatively diversified plant cover. On the plateau, the extensive occurrence of humiferous soils incorporating charcoal indicates a steppe vegetation with some conifers during the Kurtak Ia to Kurtak VIII episodes. Laterally the environment changes to a tree cover dominated by spruce in the depression of Chani. In addition, as suggested by previous pollen data from the southern edge of Berezhekovo sector (Drozdov *et al.,* 1990), not only spruce but also fir was able to colonise the bottom of lateral gullies. On the other hand, the Tcherniakovsky Soil (brown boreal soil type) developed on top of the Chaninsky Loess, may indicate moister conditions. Such climatic context is also in good agreement with predominating rill-wash during deposition of the laminated silts of the Chani Bay Complex, as well as with the pollen content of units CB6 and CB7 (*cf.* § 4.4.2).

The loess-like deposits of the Kurtak Pedocomplex, extensively distributed along the slopes and on the plateau, indicate aeolian input during colder and drier episodes. At the edge of the Chani Valley, the transition from warm to cold conditions is marked by humus bearing colluvium incorporating wood remains sometimes concentrated in compact layers by rill-wash. In particular the changing climatic environment is observed in the sandy silts following the humus bearing colluvium; it is marked by a clear regression of spruce together with the development of steppic elements and other herbaceous plants which become dominant after ca 30,000 BP in units CB2 and CB1 of the Chani Bay Complex. The climatic cooling is also clearly observed on the plateau where the aeolian input is generally linked to cryogenic processes affecting the humus bearing horizons, including two generations of ice wedges recording permafrost conditions (Black, 1976; Haesaerts and Van Vliet-Lanoë, 1981). In the Trifonovka and Kurtak sectors, these wedges open at the base of unit KP3 dated around 31,500 BP and also at the top of the tundra gley close to 26,000 BP which caps the Chani Bay Complex in the P31-Chani area (subunit 1-1).

The pollen and pedosedimentary data show a rather diverse vegetation on the western slope of the Yenisei Valley between ca 40,000 and 26,000 BP, induced by an unstable climate. The steppe component in units CB5 to CB1 of the Chani Bay Complex, including in the humiferous soils, strongly suggests that steppe formed the landscape of the area throughout the period considered. The pollen increase of the arboreal taxa during warm climatic episodes can be interpreted as expansions of boreal tree populations, limited to small valleys but able to expand up to the edges of the plateau during periods of climatic improvement. This is suggested by charcoal preserved in the humiferous soils of the Trifonovka and Kurtak sectors. Consequently, and contradicting the suggestion of Chlachula *et al.* (1997), the Kurtak pollen record is not understood as an evidence that a southern expansion of the limit of taiga occurred in the northern Minusinsk Basin during short duration oscillations at the time of the Kurtak Pedocomplex between ca 40,000 and 26,500 BP. On the contrary, a temporary extension of taiga during the development of the Tcherniakovsky Soil cannot be excluded.

Finally it is important to consider the climatic parameters that controlled the environmental variations in the Kurtak region during this long period. When we consider the present-day distribution of the vegetation in the Minusinsk Basin (*cf.* § 2), it is probable that the recorded oscillations were mainly induced by variations in precipitation rather than in temperature. Nevertheless, it is obvious that the negative oscillations between the positive episodes Kurtak VIII to Kurtak Ia were also related to phases of climatic cooling as indicated by the cryogenic processes.

5.3 - CHRONOLOGICAL SETTING

The high-resolution chronology of the Kurtak sequence is based on ca 100 radiocarbon dates. In particular the coherent series of 66 dates between 25,710 and 36,800 BP obtained for high quality wood samples precisely located in the stratigraphy of the Chani Bay Complex is unique (fig. 6). This dataset made it possible to control the chronological significance of the dates and to specify their relationship to the pedosedimentary and climatic events (figs 7 and 8).

A first series of dates concerns stumps, fragments of branch or bark preserved within the humiferous horizons of subunits 5-2, 5-1, 4-3, 4-2, 3-2, 2-2. In this case, the wood samples are contemporaneous with the pedogenesis and allow dating the process of soil formation as well as the corresponding climatic episode. In the same way, the stumps preserved in the upper part of unit CB1 at P31-A and P31-B are probably contemporaneous with the formation of the tundra gley which caps the Chani Bay Complex. Moreover, in some cases, as for subunits 5.2

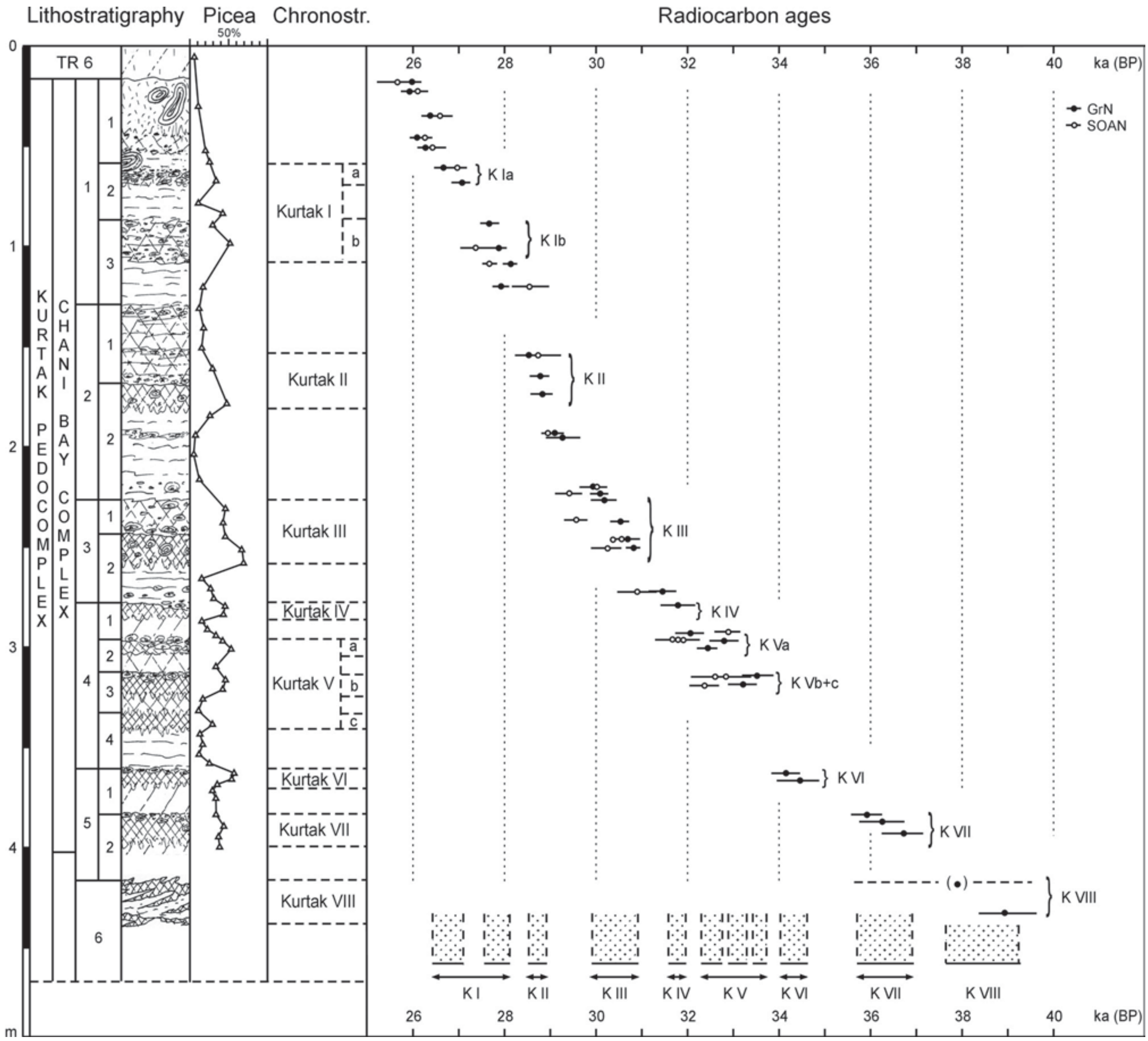

Fig. 8: Time spans and chronological limits of the climatic episodes with regard to the distribution of the radiocarbon dates in stratigraphy and time scale.

Fig. 8 : Espaces de temps et limites chronologiques des épisodes climatiques en regard de la distribution des dates ^{14}C *dans la stratigraphie et l'échelle de temps.*

and 3.2, the main phase of pedogenesis dated on wood remains present in the middle part of the soil can even be distinguished from the final phase of the pedogenesis related to the wood debris preserved in the upper part of the soil as they provided younger radiocarbon ages.

A second series of dates is obtained on wood fragments often concentrated in lenses in the humiferous sandy silt and in the loess-like sediments overlying the pedological horizons (subunits 3-1, 2-1, 1-3 and 1-2). In this case, the coherence in the radiocarbon ages, which are somewhat younger than those from the subjacent horizons, shows that the majority of the wood fragments are contemporaneous with the sedimentation phase which follows the pedogenesis. Nevertheless, a few inversions of dates indicate more complex processes. In particular the wood concentration of subunit 4-2 in sections P31-A and P31-B (fig. 6), whose large time span ranges between 33,200 and 31,750 BP, indicates a reworking of part of the woody material coming from the subjacent humiferous horizon 4-3. In the same way, the dates 32,110 and 32,450 BP obtained from the latter horizon appear too young compared to the dates 33,250 and 33,580 BP provided by the same horizon (4-3). This inversion can be explained by the horizontal intrusion of roots from units 4-2 or 4-1 into horizon 4-3. Fortunately such disturbances appear exceptional in the sequence; they are mainly related to the wood concentration of subunit 4-2 and do not affect the high coherence of the whole chronological frame of the Chani Bay Complex.

Concerning the Kurtak Pedocomplex, a precise relationship between pedosedimentary dynamics and the charcoal dates from the solifluated humiferous horizons appears more difficult to establish. However, our results provide chronological time spans which can support direct comparison with the ages of the equivalent units in the Chani Bay Complex (fig. 7), in particular with the ages corresponding to the final phases of the climatic episodes Kurtak III and Kurtak II. Under such conditions, charcoal of the Kurtak Pedocomplex would be mainly the product of natural fires of the vegetation made more vulnerable at the transition to phases of climatic degradation (Van Vliet-Lanoë, 1985).

Taken together, the dates for the Kurtak Pedocomplex and the Chani Bay Complex allow excellent chronological control of the sedimentary and pedological processes regarding the climatic succession of the system (fig. 8). The climatic events Kurtak VIII to Kurtak Ia in the period ranging from ca 39,000 to ca 26,500 BP can be dated with a time resolution of a few centuries or less (fig. 9). In some cases, for instance Kurtak V, the chronological limits were fixed taking into account the fact that some rather large dispersion of the dates could be due to reworking and intrusive processes as discussed above.

5.4 - CHRONOSTRATIGRAPHY

5.4.1 - The regional background

The climatic context and the chronological framework established for the Kurtak Pedocomplex, the Tcherniakovsky Soil and the Chani Bay Complex confirm the ascription of these pedosedimentary successions to the Karga Stage as well as to MIS 3 (Derevianko *et al.*, 1992; Drozdov *et al.*, 1999; Chlachula, 2003). This interpretation is also in agreement with the series of luminescence dates obtained by Zander *et al.* (2003) for the middle part of the Late Pleistocene sequence at Kurtak (figs 3 and 4). In Central Siberia, the Karga Stage generally includes two interstadial phases separated by the Zighan-Konoshchel cooling (Volkov and Orlova, 2000; Zykin *et al.*, 2000). However, at Kurtak, the sequence between ca 45,000 and 26,000 BP is more complex and can be divided in four distinct periods with specific pedosedimentary and climatic signatures (fig. 9).

a) During the first period, between ca 45,000 and 40,000 BP, the landscape remains stable after the deposition of the Chaninsky Loess. The Tcherniakovsky pedogenesis of brown boreal type developed on the plateau during a relatively humid climatic phase. During the same time the laminated sandy silts were deposited in the Chani depression under vegetation cover with spruce and pine.

b) The second period ranging from ca 40,000 to 33,700 BP, is characterised by less stable and less humid conditions. Humiferous soils developed during the warmer episodes Kurtak VIII to VI with spruce vegetation in the depressions while loess-like aeolian input started on the high parts of the landscape during the cold episodes.

c) The third period has a shorter duration: interstadial conditions prevail with dominance of spruce in the Chani Valley during the episodes Kurtak V and IV dated between ca 33,700 and 31,700 BP.

d) The last period records the interstadial episodes Kurtak III to Kurtak Ia and reflects the increasing influence of cold conditions favouring an expansion of steppe type vegetation. This climatic trend is also marked by at least two episodes of permafrost with development of large polygonal net of ice wedges on the plateau, at ca 31,500 BP and at 26,000 BP before the deposition of the Trifonovo Loess ascribed to the Sartan Stage.

According to this scheme, the three periods between ca 45,000 and ca 31,700 BP can be assigned to the Malokheta interstadial phase (Early Karga Stage), which is well dated between 42,000 and 32,500 BP in West Siberia (Volkov and Orlova, 2000). In particular, at Ust-Meret and Kargopolovo along the Ob River, several generations of conifer stumps provided ^{14}C dates of 41,075, 36,850 and 33,450 BP comparable with the ages obtained for the episodes Chani I, Kurtak VII and Kurtak V. The cold episode with ice wedges around 31,500 BP (between Kurtak IV and Kurtak III) would be contemporaneous with the Zighan-Konoshchel cold episode dated between 33,000 and 31,000 BP in the regional sequence (Volkov and Orlova, 2000). Similarly, the episodes Kurtak III to Kurtak I have their equivalent in the Lipovo-Novoselovo warm episode (Late Karga Stage) between 31,000 and 25,000 BP, well documented for the Novosibirsk region. Also here, a horizon of stumps was dated 30,870 BP in the Krasny Yar site on the Ob River, an age similar to that of the Kurtak III episode.

5.4.2 - Extended system

The correlation between the Kurtak sequence and the middle pleniglacial loess-palaeosol successions west of

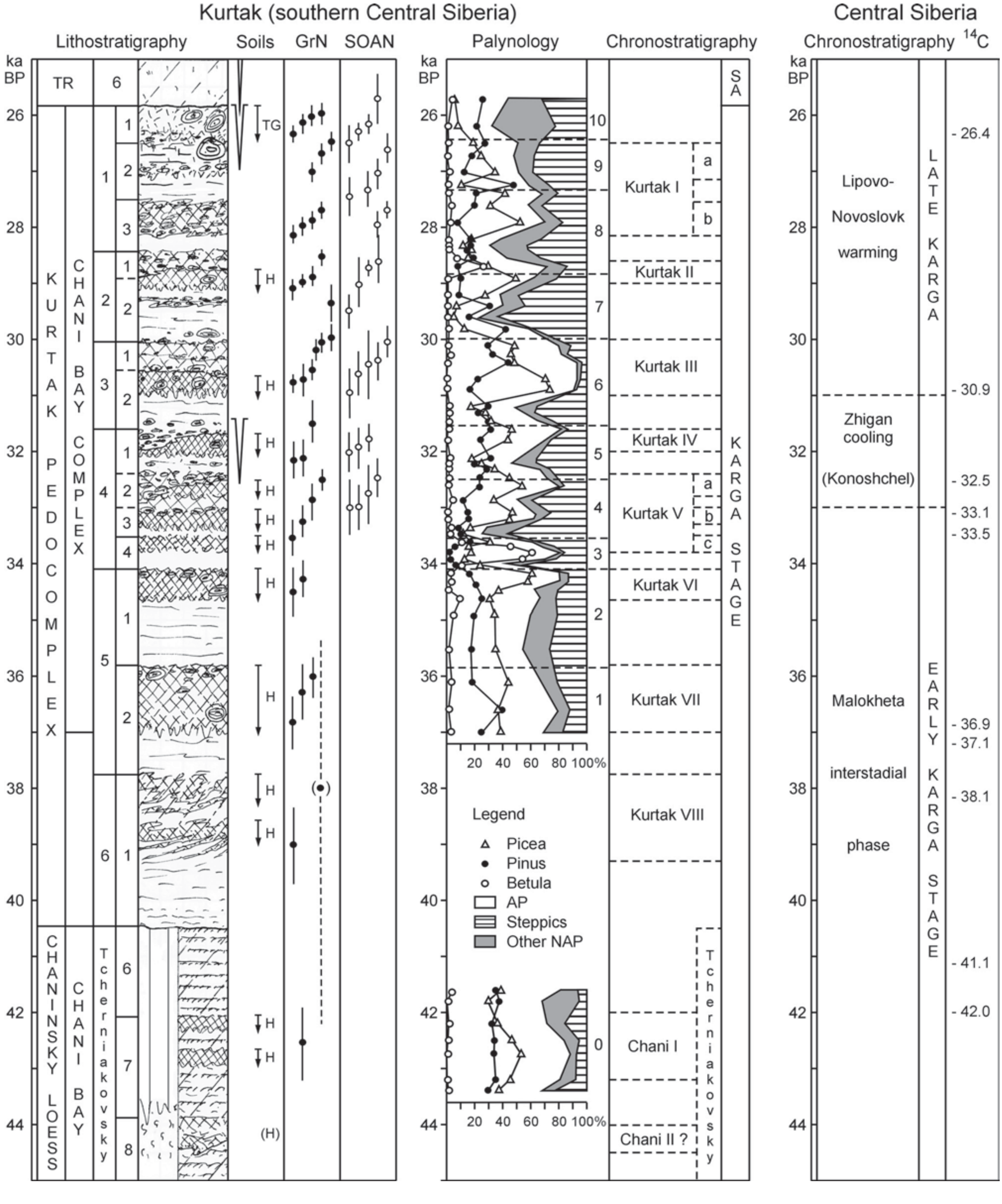

Fig. 9: Chronological setting of the Karga Stage at Kurtak with regards to the climatic succession of Central Siberia. Graphic symbols and abbreviations are the same as in figure 3.
Fig. 9 : Chronologie du Stade de Karga à Kurtak et comparaison avec la succession climatique de Sibérie centrale. Symboles graphiques et abréviations comme dans la figure 3.

the Urals remains a difficult task due to the discontinuous character of the latter records (Haesaerts, 1985; Svoboda *et al.*, 1994; Haesaerts and Teyssandier, 2004). Nevertheless, some parts of these records are well documented locally in the archaeological sites of Central and Eastern Europe which have provided high-resolution climatic and chronological data for limited time spans of MIS 3 (fig. 10). For example, in Lower Austria and Southern Moravia two sets of double interstadials named Willendorf-Schwallenbach I and Schwallenbach II-Schwallenbach III correspond to the periods ca 42,000-37,500 BP and 32,200-30,000 BP, respectively (Damblon *et al.*, 1996; Haesaerts *et al.*, 1996). Furthermore, in the East Carpathian Area, the Palaeolithic sites Mitoc-Malu Galben (Romania) and Molodova V (Ukraine) record a distinct succession of four interstadial events labelled

Malu Galben 12, Molodova 10-2, Molodova 10-3 and Malu Galben 8 dated between ca 32,500 and 26,500 BP (Haesaerts *et al.*, 2003). The chronological frame of the lower part of the Molodova V sequence prior to ca 33,000 could not be established due to the lack of datable material (fig. 10). At Kostienki 14 in the Middle Don Basin (Central Russia) the lower humic bed provides a detailed complementary succession for the period 37,200-32,500 BP encompassing four interstadial events related to the humiferous horizons LH4 to LH1 preserved *in situ* (Sinitsyn *et al.*, 2002; Haesaerts *et al.*, 2004). The chronological and climatic resolution of the upper humic bed

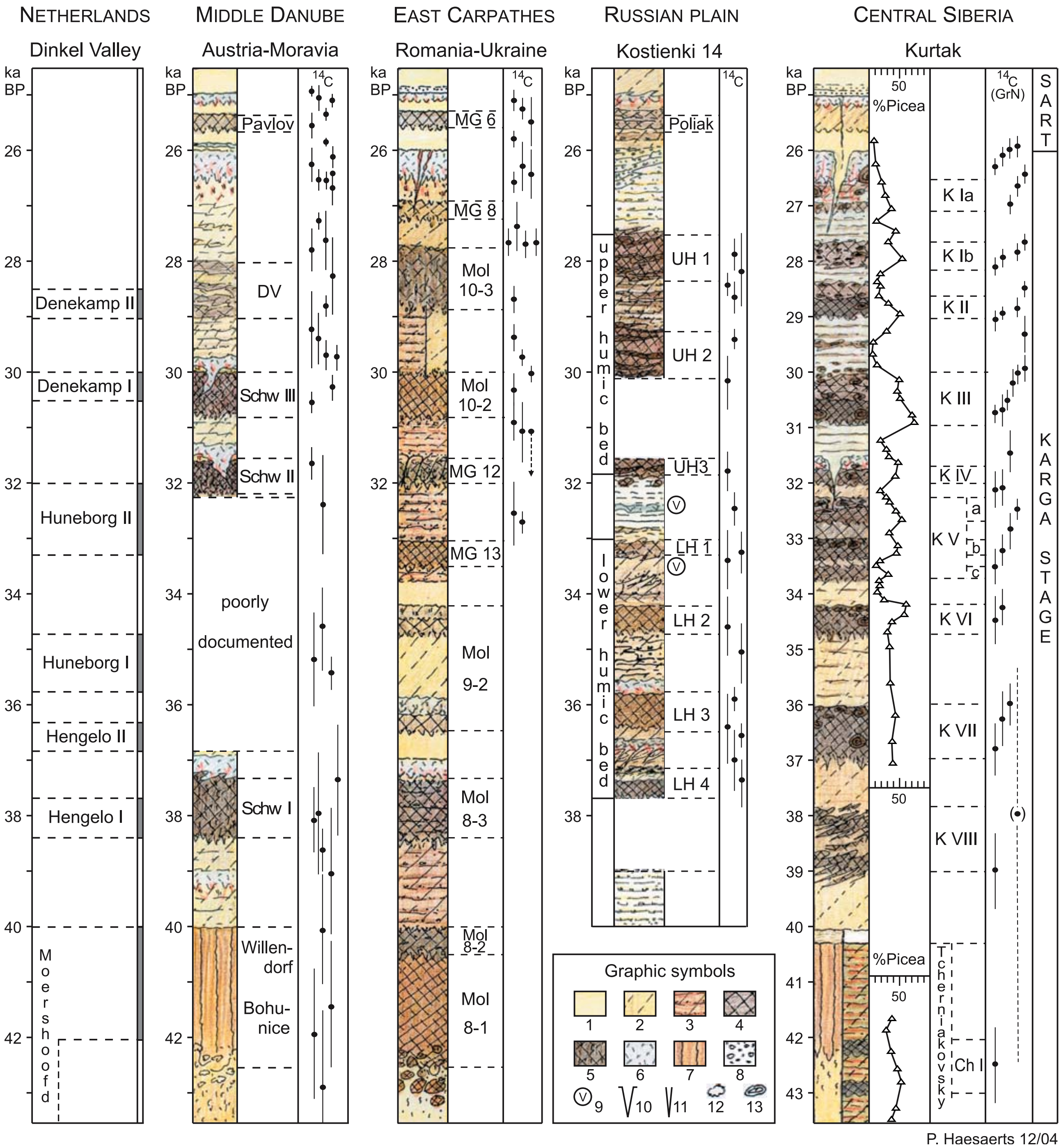

Fig. 10: Correlation scheme between the sequences of Kurtak (Central Siberia), Central Russia (Kostienki 14), East Carpathes (Romania-Ukraine), the Middle Danube Basin (Austria-Moravia) and the Netherlands (Dinkel Valley).
Graphic symbols. 1: loess; 2: light brown loess-like silt; 3: loam; 4: humiferous loess-like silt; 5: bioturbated humiferous horizon; 6: bleached horizon (tundra gley); 7: brown boreal soil (B horizon); 8: gravel; 9: volcanic ash; 10: ice wedge pseudomorph; 11: frost wedge; 12: secondary carbonates (concretion); 13: wood remain.
Abbreviations. DV: Dolni Vestonice; Schw: Schwallenbach; MG: Malu Galben; Mol: Molodova; Poliak: Poliakov; UH: upper humic horizon; LH: lower humic horizon; K: Kurtak; Ch: Chani.
Fig. 10 : Schéma corrélatif entre les séquences de Kurtak (Sibérie centrale), de Russie centrale (Kostienki 14), du domaine Est-Carpatique (Roumanie-Ukraine), du bassin moyen du Danube (Autriche-Moravie) et des Pays-Bas (Dinkel Valley).
Symboles graphiques. 1 : loess ; 2 : limon loessique brun clair ; 3 : limon ; 4 : limon loessique humifère ; 5 : horizon humifère ; 6 : horizon déferrifié (gley de toundra) ; 7 : sol brun boréal (horizon B) ; 8 : cailloutis ; 9 : cendre volcanique ; 10 : pseudomorphose de coin de glace ; 11 : fente de gel ; 12 : concrétion calcaire ; 13 : restes de bois.
Abréviations. DV : Dolni Vestonice ; Schw : Schwallenbach ; MG : Malu Galben ; Mol : Molodova ; Poliak : Poliakov ; UH : horizon humifère supérieur ; LH : horizon humifère inférieur ; K : Kurtak ; Ch : Chani.

dated between ca 31,760 and 27,890 BP is rather poor due to cryogenic processes (Sinitsyn, 1996).

Despite their precision, these loess-palaeosol successions cannot be used as continuous reference records for MIS 3. They are often located on slopes where solifluction and erosion were active. For these reasons, it is interesting to compare the MIS 3 climatic signal of Kurtak with the climatic succession of the Dinkel Valley in the Netherlands (Ran, 1990; van der Hammen, 1995). The latter is one of the best documented sequences for this period in Western Europe. The comparison with the Dinkel Valley record is based on the following points (table 5).

1) Hundreds of ^{14}C dates in parallel with pollen data were retrieved from many peat layers in the limited fluviatile area of the Dinkel Valley.

2) The chronology covers a long time span between ca 42,000 and 28,500 BP.

3) The whole set of radiocarbon and palaeoenvironmental data enabled the reconstruction of a succession of climatic oscillations which shows many similarities with the one recorded at Kurtak (fig. 10).

6 - CONCLUSION

During the last decade, much new information has been obtained for the Late Pleistocene succession at Kurtak on loess stratigraphy, palaeopedology, chronology and palaeobotany. The section P29-north at Berezhekovo provided a detailed pedosedimentary succession for the Kamenny Log Soil and for the Sukhoy Log Pedocomplex encompassing the main climatic events of MIS 5. The sequence recorded for the Karga Stage (MIS 3) within the Kurtak Pedocomplex and the Chani Bay Complex is now well documented. In particular, the Karga sequence shows almost 14 warm climatic events, the main part of this sequence being framed by ca 100 radiocarbon dates between 25,710 and 42,520 BP, mainly on conifer wood remains. Cold climatic episodes can be inferred from loess-like sedimentation, cryogenic processes, tundra gley and high pollen percentages of steppe herbs and forbs. Warm climatic episodes can be recognised by high pollen percentages of conifers, especially *Picea* mainly in the humiferous horizons.

The significance and uniqueness of this succession and the high accuracy and precision of the results are due to a variety of factors that favoured the preservation of the Kurtak sequence.

- A first factor concerns the strong continental background of the Kurtak region at the northern edge of the Minusinsk Basin. The position of the site along the valley slope of the Yenisei allowed a semi-continuous loess sedimentation during the Late Pleistocene fed by the fluviatile deposits originating from the Sayan Ranges.

- The geomorphological setting of the Minusinsk Basin regarding the northern Sayan foothills is of main importance because it determines a strong sensitivity of the vegetation to changes in precipitation. This transitional situation was especially favourable for recording shifts in vegetation and climate, even during short climatic oscillations of the Karga Stage.

- A third and exceptional factor is the position of the site along the Krasnoyarsk reservoir. This provided access to a Late Pleistocene loess sequence reaching a thickness of 25 m, locally preserved 65 m above the Yenisei valley floor.

- The fourth factor concerns the good preservation state of the botanical remains in the Chani Bay Complex which forms the core of the palaeobotanical reconstruction and the chronological setting of the Karga Stage (MIS 3). Such a preservation state is related to the wet environment of the valley of Chani but also to an interaction between sedimentation and freezing processes, as indicated by the limited erosion during deposition of the Chani Bay Pedocomplex. These conditions existed also

Dinkel ^{14}C age limits (ka BP)	Netherlands interstadials	Kurtak oscillations	Kurtak ^{14}C age limits (ka BP)
ca 28.5 to 29.0	Denekamp II	Kurtak II	ca 28.6 to 29.0
ca 30.0 to 30.5	Denekamp I	Kurtak III	ca 30.0 to 31.0
ca 32.0 to 33.3	Huneborg II	Kurtak IV	ca 31.7 to 32.0
		Kurtak V	ca 32.2 to 33.7
ca 34.7 to 35.7	Huneborg I	Kurtak VI ?	ca 34.2 to 34.7
ca 36.3 to 36.8	Hengelo II	Kurtak VII	ca 36.0 to 37.0
ca 37.7 to 38.4	Hengelo I	Kurtak VIII	ca 37.8 ? to 39.0 ?
ca 40.0 to 45.0 ?	Moershoofd	Tcherniakovsky + Chani I ?	ca 40.0 to 45.0 ?

Table 5: Proposed date limits and correlation between interstadials for the Dinkel Valley (the Netherlands) and Kurtak (Central Siberia).
Tab. 5 : Dates limites proposées et corrélations entre les interstades mis en évidence dans la Dinkel Valley (Pays-Bas) et à Kurtak (Sibérie centrale).

at the time of the Trifonovo Loess, during the Sartan Stage, the whole loess body remaining probably frozen up to the Holocene.

Consequently, the Kurtak sequence constitutes the best documented palaeoenvironmental and chronological record currently available for the Karga Stage in the loess field of southern Central Siberia. In particular, the high-resolution record results from the presence of a pedosedimentary succession rich in wood remains preserved in a depression at the edge of the Chani Valley, which connects laterally with the loess cover on the plateau. This situation is exceptional compared with the majority of the loess-palaeosol sequences of Central Siberia that have provided records for MIS 3. Indeed, these sequences were generally preserved along large rivers in a context favouring erosion and present fragmentary records whose connection with the loess cover on the slopes remains problematic. The significance and the coherence of the Kurtak sequence are even more strengthened by the numerous common characteristics it shares with the palaeoclimatic and chronological sequence of the Dinkel Valley in the Netherlands and with some records of the European loess belt during MIS 3. These independent palaeoclimatic signals demonstrates the global character of the Siberian climatic signature and emphasizes the predominance of highly unstable environmental conditions during MIS 3 on the scale of the Eurasian continent from Central Siberia to the Atlantic front, throughout Eastern and Central Europe.

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